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The Journal of

THE ROYAL AERONAUTICAL SOCIETY

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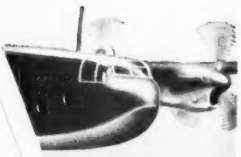
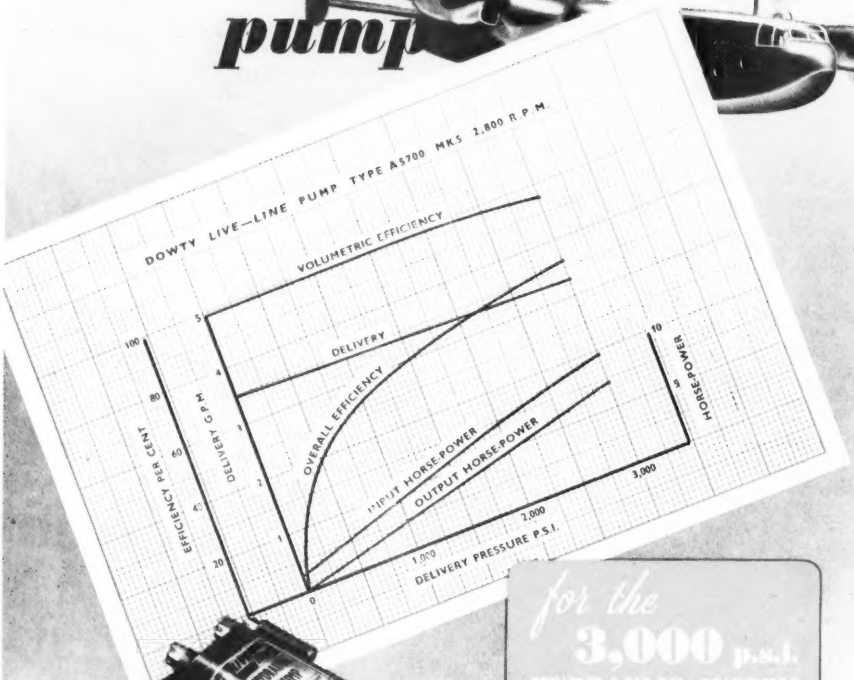
DOWTY

LIVE-LINE pump





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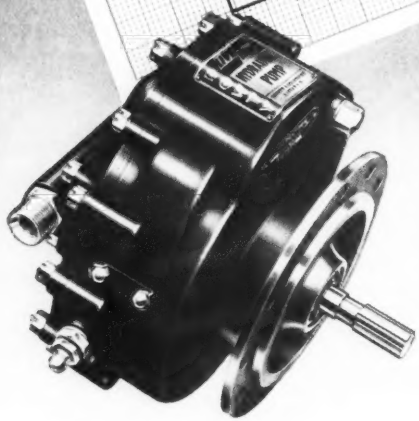
3,000 p.s.i.

HYDRAULIC SYSTEM



The DOWTY LIVE-LINE PUMP is pre-eminent for hydraulic systems operating at pressures up to 3,000 p.s.i. Fully automatic, it gives constant delivery up to the reaction point and thereafter acts as a variable delivery pump at constant pressure.

The pump weighs only 10lbs. and combines the functions of cut-outs, pressure regulators and accumulators with absolute reliability of operation. This results in important weight-saving and a simplified system.

A range of pumps offering widely varying operating speeds, pressures and displacements is now available.

DOWTY EQUIPMENT LIMITED, CHELTENHAM, ENGLAND

THE ROYAL AERONAUTICAL SOCIETY

4 HAMILTON PLACE, PICCADILLY, LONDON, W.1

MARCH NOTICES 1948

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

CONTENTS OF THE MARCH JOURNAL

The Wright Brothers.

Gas Turbine Accessory Systems, by O. N. Lawrence, A.F.R.Ae.S.

The Nature of the Distortion of Swept-Back Wings, by Professor G. T. R. Hill, M.Sc., F.R.Ae.S.

Correspondence.

ORVILLE WRIGHT

The following cable was sent by the President, Dr. H. Roxbee Cox, to the Institute of the Aeronautical Sciences on the death of Orville Wright on the 30th January 1948:—

" The President, Council and all members of the Royal Aeronautical Society have learnt with profound regret of the death of that great American, Orville Wright, to whom with his brother Wilbur, the Society awarded their first Gold Medal. May his passing remind us all of his lifelong wish that the tremendous consequences of their pioneer work shall be a great instrument of peace and friendship.

Roxbee Cox, President, Royal Aeronautical Society."

The cable was forwarded by the Institute to the executors of Mr. Wright at Dayton, Ohio.

ALL-DAY DISCUSSION

It is regretted that owing to unforeseen circumstances the All-day discussion on Safety in Civil Aviation arranged for Saturday, 3rd April 1948 has been postponed.

EASTER HOLIDAYS

The offices of the Society will be closed from 5 p.m. on Thursday, 25th March 1948 until 9 a.m. on Tuesday, 30th March 1948.

ROYAL AERONAUTICAL SOCIETY DATA SHEETS

The Royal Aeronautical Society has prepared data sheets on Aerodynamics and Stressed Skin Structures for the use of all technicians engaged in aviation.

The Aerodynamic data sheets, numbering 66, are now available at a price of 1/- to members and 2/- to non-members of the Society. These sheets give information and data on most aerodynamical problems connected with aircraft.

The sheets on Stressed Skin Structure are now being printed and will be available shortly.

A full list of sheets may be obtained from the Secretary, The Royal Aeronautical Society, 4 Hamilton Place, London, W.1.

CANCELLED LECTURE

The lecture which was to have been given by Mr. W. E. W. Petter, B.A., F.R.Ae.S., on The Aerodynamic Problems of High Altitude Design on Thursday, 15th April 1948, has been cancelled. *Instead,* Mr. E. S. Calvert, B.Sc., A.R.C.Sc.I., will lecture that night on Visual Aids for Low Visibility Conditions.

ANNUAL GENERAL MEETING

Notice is hereby given that the Annual General Meeting of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Friday, 7th May 1948, at 6.0 p.m., in the offices of the Society, 4 Hamilton Place, London, W.1.

AGENDA

1. To read the Notice convening the Meeting.
2. To receive and deliberate upon the Report of the Council on the state of the Society and the Balance Sheets of Aerial Science Limited and Aeronautical Trusts Limited for the year ended 31st December 1947.
3. To receive the names of those elected to Council for the years 1948-1951.
4. To announce the List of Fellows elected by the Council in accordance with Rule 4.
5. To elect the Auditors for the ensuing year for Aerial Science Limited and Aeronautical Trusts Limited.
6. Any other business.

By Order of the Council,
J. LAURENCE PRITCHARD,
Secretary.

Light refreshments will be served before the Meeting at 5.30 p.m.

1*st March* 1948

ELECTION TO COUNCIL

Attention is drawn to the following rules for election to Council. Nominations must be received by the 10th April 1948.

Nomination forms may be obtained from the Secretary.

Extract from Rule 22

" The twenty-one ordinary members shall be nominated and elected from among the members of the Society. At the date of their election at least ten shall be Fellows, and one at least shall be in each of the following classes, Associate Fellow, Associate and Graduate.

" Of the ordinary members of the Council, that number necessary to create seven vacancies shall retire annually. The retiring members shall be those with the longest service since election, but they shall be eligible for re-election.

" Nominations of candidates for election to the Council must be received by the Secretary not later than 10th April in each year and shall include statements in writing by the candidates that they are willing to serve. The nomination forms shall be signed by one proposer and two seconders, all of whom shall be voters."

Extract from Statute 4.

" The Founder Members, Fellows, Associate Fellows and Associates are herein and in the Rules collectively referred to as Voters."

GRADUATES' AND STUDENTS' SECTION

Annual General Meeting

The Section's Annual General Meeting will be held on Wednesday, 21st April 1948, at 7 p.m., in the offices of the Society, 4 Hamilton Place, W.1.

AGENDA

1. To read the minutes of the previous Annual General Meeting.
2. To receive the Annual Report.
3. To elect officers and committee for 1948-49.
4. To consider any other business.

Nominations for officers and committee, signed by a proposer and seconder, and notice of business under item 4 should reach the Hon. Secretary, J. G. Roxburgh, 62 Fitzjohns Avenue, London, N.W.3, not later than three days before the meeting.

BADEN POWELL MEMORIAL PRIZE

The Baden Powell Memorial Prize has been awarded to Aircraftsman H. S. Liner who was considered by the examiners to be the best candidate in the December 1947 Associate Fellowship examinations. Mr. Liner took the examination at Bulawayo, Southern Rhodesia.

ELLIOTT MEMORIAL PRIZE

The Elliott Memorial Prize has been awarded to 582280 Milne, W. C., Fitter II (E)—Cpl./App./Air, the Aircraft Apprentice of the February 1945 Entry, who obtained the highest marks in the General Studies Examination.

The prize will be presented at the Passing Out Prize Giving at R.A.F. Station, Halton, on 10th March 1948.

CIERVA MEMORIAL PRIZE ESSAY 1947/48

The closing date for entries for the Cierva Memorial Prize Essay for 1947/48 has been extended to 31st March 1948.

LEICESTER BRANCH

Mr. F. Watkins, A.F.R.Ae.S., has been elected Secretary of the Leicester Branch. His address is: c/o Auster Aircraft Ltd., Rearsby Aerodrome, Rearsby, Leicester.

FLIGHT TESTING AT HIGH SUBSONIC SPEEDS by H. Davies, B.A., M.Sc., A.F.R.Ae.S.—*Summary of Lecture to be given on Thursday, 18th March* 1948.

A survey will be made of recent developments in flight research at high Mach numbers, with special reference to work done at the Royal Aircraft Establishment.

The methods and technique of flight testing at high speeds will be described in detail and the limitations imposed by inherent difficulties of the work discussed. Refinements in instrumentation needed to cope with high Mach number phenomena will also be discussed.

Flight measurements of compressibility effects on drag, lift, stability and control characteristics and so on, will be analysed, with the aid of pressure distributions, wake-measurements and observations of the flow by means of tufts. The precise origin of the drag rise will be discussed in some detail, with particular reference to scale effects. Considerable emphasis will be placed on comparisons with wind tunnel and other model tests, since it is felt that this constitutes probably the most important aspect of flight research at high speeds. It will be shown that over a wide range of problems existing high speed wind tunnels can give results directly applicable to flight conditions.

Finally, some consideration will be given to future trends in flight research and suggestions made regarding the best methods of dealing with the problems likely to arise.

LECTURE PROGRAMME—1948

The Lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, S.W.1 (by permission of the Council of the Institution) unless otherwise stated. Tea will be served at 5.30 p.m.

Visitors are welcome, but should obtain tickets through a member of the Society.

Thursday, 18th March 1948—Flight Testing at High Subsonic Speeds, by H. Davies, B.A., M.Sc., A.F.R.Ae.S.

Thursday, 15th April 1948—Visual Aids for Low Visibility Conditions, by E. S. Calvert, B.Sc., A.R.C.Sc.I.

Thursday, 27th May 1948—The 36th Wilbur Wright Memorial Lecture will be read by A. Gouge, B.Sc., F.R.Ae.S.

BELFAST BRANCH

Tuesday, 16th March 1948—Inside Occupied Japan, by William Courtenay, M.M., A.R.Ae.S.

At the Assembly Hall, Belfast College of Technology, at 7.30 p.m.

BIRMINGHAM BRANCH

Monday, 5th April 1948—The Development of Stressed Skin Construction, by Dr. D. M. A. Leggett, A.F.R.Ae.S.

At the Chamber of Commerce, Birmingham, at 7.30 p.m.

BRISTOL BRANCH

Monday, 22nd March 1948—Operation of Civil Transport Aircraft, by N. E. Rowe, C.B.E., F.R.Ae.S., Controller of Research and Long Term Development, British European Airways.

Wednesday, 14th April 1948—Film Night and Annual General Meeting.

All meetings will be held in the Conference Room, Bristol Aeroplane Co. Ltd., Filton House, at 6.0 p.m.

GLASGOW BRANCH

Thursday, 25th March 1948—Lecture and Film Show, by Dr. Hooker of Rolls-Royce Ltd., at Hillington.

Tuesday, 6th April 1948—Visit to The India Tyre and Rubber Co., Inchinnan.

Saturday, 8th May 1948—Visit to Prestwick Airport. At 3 p.m.

Tuesday, 8th June 1948—Visit to The Glasgow Herald Office.

Saturday, 3rd July 1948—Visit to The Blackburn Aircraft Ltd., Clyde Factory, Dumbarton.

Thursday, 26th August 1948—" Lecturettes." At The Grand Hotel, Charing Cross, Glasgow.

Tuesday, 28th September 1948—A Film Evening, at 7.30 p.m., at Prestwick Airport.

Thursday, 28th October 1948—Lecture by a Branch Member, at 7.30 p.m., at The Grand Hotel, Charing Cross, Glasgow.

Tuesday, 30th November 1948—" Lecturettes," at 7.30 p.m., at Prestwick Airport.

Thursday, 23rd December 1948—ANNUAL GENERAL MEETING, at The Grand Hotel, Charing Cross, Glasgow.

Members are requested to notify the Secretary at least one week before any of the visits, if they intend to be present.

Visits are confined to members only, but visitors are welcomed at all Lectures, Lecturettes and Film Shows.

GLOUCESTER AND CHELTENHAM BRANCH

Wednesday, 7th April 1948—Annual General Meeting followed by Film—at Cheltenham.

In the Chemistry Lecture Theatre, Grammar School, Cheltenham, at 7.30 p.m.

LEICESTER BRANCH

Wednesday, 10th March 1948—Structural Testing, by Dr. P. B. Walker, Ph.D., M.A., F.R.Ae.S., head of the Structures Department, R.A.E., at 7 p.m.

LUTON BRANCH

Wednesday, 7th April 1948—Rocket Propulsion and Inter-Planetry Flight, by A. V. Cleaver, A.R.Ae.S., at the George Hotel, Luton, at 7 p.m.

MANCHESTER BRANCH

Thursday, 1st April 1948—Flight Refuelling, by C. H. Latimer-Needham.

At the Reynolds Hall, College of Technology, at 7.30 p.m.

PRESTON BRANCH

Wednesday, 10th March 1948—Bird Flight, by Captain J. L. Pritchard, Hon.F.R.Ae.S. At the Harris Technical College, Preston, at 7.15 p.m.

SOUTHAMPTON BRANCH

Wednesday, 17th March 1948—A Survey of Fighter Handling Qualities from 1936 to the Present Day, by J. K. Quill, O.B.E., A.F.C., Chief Test Pilot, Supermarine Works, Vickers-Armstrongs Ltd.

YEOVIL BRANCH

Thursday, 11th March 1948—Title to be fixed; P. G. Masefield, M.A.(Eng.), F.R.Ae.S.

Thursday, 25th March 1948—Recent Developments in Flying Boats, by H. Knowler, F.R.Ae.S.

Thursday, 1st April 1948—Annual General Meeting and Film.

Meetings are usually held at the Park School, Prince's Street, Yeovil, at 6.30 p.m.

GRADUATES' AND STUDENTS' SECTION

Wednesday, 14th April 1948—The Influence of the Recent Civil Airworthiness Requirements on Civil Aircraft Design, by W. Tye, B.Sc., F.R.Ae.S., Air Registration Board.

Tuesday, 11th May 1948—The Light Aeroplane and the Future of Private Flying, by P. G. Masefield, M.A., F.R.Ae.S., Director General of Long Term Planning and Projects, Ministry of Civil Aviation.

All meetings will be held in the Library of the Royal Aeronautical Society, 4 Hamilton Place, W.1, at 7.30 p.m. *The Library will be open at 7 p.m.*

ANNUAL SUBSCRIPTIONS OF MEMBERS

Members are reminded that their annual subscriptions became due on 1st January 1948. The present rates are:—

	Home	Abroad
	£ s. d.	£ s. d.
Fellows	5 5 0	4 4 0
Associate Fellows	4 4 0	3 3 0
Associates	*3 3 0	*3 3 0
Graduates (aged 21-25)	2 2 0	2 2 0
Graduates (aged 26-28)	2 12 6	2 12 6
Students (aged under 21)	1 1 0	1 1 0
Students (aged 21 and over)	1 11 6	1 11 6
Companions	3 3 0	3 3 0
Founder Members	2 2 0	2 2 0

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d.

It will avoid delay and confusion when sending remittances for subscriptions if members will state their name clearly and give their address and grade of membership.

Remittances should be made payable to either the Royal Aeronautical Society or Aerial Science Ltd.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

JOURNAL BINDING

Because of increased costs, the prices of binding of Journals will be as follows:—

1947 Volume 15/-.
Previous Volumes 17/-.

Journals should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the office of the Society.

NEW MEMBERS

Associate Fellows

John Lindsay Allen, Arthur Charles Boswell (from Graduate), David Cardwell (from Graduate), Geoffrey James Barnard Hall (from Graduate), John Glyn Jones (from Associate), Meyer Julian Kemper (from Associate), Herbert Joe Knevitt, Victor Henry Knight, John Brown Lambie, James Arnold Latham, Kenneth John Leighton (from Graduate), Norman Spencer Makins (from Graduate), Alfred Charles Marshall, Edwin John Ewart Newman (from Graduate), Francis Joseph Newton (from Graduate), Robert Deans Peggs, Arthur Ernest Polden, Norman Pursseil (from Graduate), Hywel Rolands Rees, Gilbert Charles Riall (from Associate), Anthony Arthur Rose (from Graduate), Charles Francis Norman Seaman, Eric William Troman, Keith Winterbotham Turner, Harry Tyler (from Graduate), Vivian Humphrey Wickham (from Graduate), John Malcolm Nicolson Willis (from Student), Arthur Jack Willshire (from Graduate), Frederick James Woodcock.

Associates

Donald Charles Allen, Peter Endsleigh Castle, Cyril Arthur Catherall, Frederick James Alfred Collins, Patrick Arthur Dean, Cecil Austin Denne, Eric George Franklin, Bernard Godfrey George Gilmore, Charles Ronald Griffiths, Arthur John Hinkley, Gordon Edward Hughes, Michael John Debenham Inskip, Eric Isherwood (from Student), George Frederick Jackson, Jacques Alecxis Kirk (from Student), Charles Henry Lang, Edwin Campbell Lawson, James William Lockley, Sidney John MacNamara, Charles Albert Martin, John Desmond Murphy, William Paul Nicol, Hayden Rece Porter, John Griffin Portlock, Robert Bisset Wight Scott (from Companion), Ronald Frederick Oliver Smith, Laurence Higgon Stopforth, David George Thorpe, Charles Horace Wells, George White.

Graduates

David Richard Blundell (from Student), Brian Arthur Howard Botting, Leslie Harvey Bridge, Stanley Milton Butler, John Edward Clough (from Student), Henry Cook, Thomas Martin Corson, William Harold Dainty, Kenneth Leslie Day (from Student), Norman Frederick Harpur (from Student), Richard Alan Harriss (from Student), Henry Brian Iles, Francis George Irving (from Student), Marcus Llewellyn Bruss Jones, Robert John Jupe, Gavin Stuart Kermack (from Student), Rene Herbert Le Claire, Eric Jesse McKenna (from Student), Denys John Mead (from Student), Stanley Bernard Newport, Donald Glyn Oliver, Forbes George de Brie Perry, Alan Vincent Rushton, Frank Smith, Roy Starmer (from Student), John Francis Tring (from Student), Anthony Roy Turley (from Student), Ronald Frederick West (from Student), William Francis Wiles.

Students

James Joseph Ansell, William James Avis, Ronald Frank Bailey, John Francis Barlow, David Alan Hughes Bird, Gerald Evan Gladwin Bishop, Brian Edward Boyce, Michael Frederick Burle, Ian Bernard Butterworth, Bernard Caiger, Dennis James Carey, Edward Christopher Carter, Arthur George Creak, Eric Ernest Denyer, John Stewart Drabble, John Derek Ellis, David Harold Frean, Kenneth Herbert Griffin, William Hodgson Haigh, John Dennis Hallett, James Michael Howe, John Clubb MacDonald, Eugene Peter McLoughlin, Ivor Armfield Payne, Lionel Chatham Pitt, Robert James Revill, Robert John Rockcliff, William Colin Ruler, Kenneth Robert John Shearwood, Peter Duncan Stewart, Jonathan Swainson, Robert Graham Taylor.

Companions

Leonard Atherton, Gordon Fryer (from Student), Curt B. A. Schiff, John Anthony Scott.

ASSOCIATE FELLOWSHIP EXAMINATION RESULTS

HOME

The following were the successful candidates in the Associate Fellowship Examination held in December 1947:—

W. J. Allen, Strength of Aeronautical Materials and Structures, Theory of Machines; J. Ansell, Pure Mathematics; R. J. Barnard, Applied Mathematics; H. G. Bell, Pure Mathematics; V. M. G. Bennett, Pure Mathematics; R. A. Berridge, Pure Mathematics, Strength of Aeronautical Materials and Structures, Design (Aircraft); G. W. Bleasdale, Theory of Machines; A. A. Blythe, Pure Mathematics, Strength of Aeronautical Materials and Structures; E. L. Bond, Applied Mathematics; F. R. J. Britten, Pure Mathematics, Strength of Aeronautical Materials and Structures; D. W. Bryer, Applied Mathematics, Theory of Machines; J. Bunting, Applied Mathematics; T. D. R. Carroll, Design (Aircraft); R. Cash, Applied Mathematics, Theory of Machines; R. S. Challender, Theory of Internal Combustion Engines; L. J. Chantler, Design (Aircraft); J. B. Chaplin, Theory of Machines; G. B. Charter, Applied Mathematics, Theory of Internal Combustion Engines; J. K. Chaudhuri, Applied Mathematics; P. Child, Pure Mathematics, J. F. Clarke, Design (Aero Engines); A. L. Cole, Pure Mathematics; K. W. Course, Design (Aero Engines); E. N. Crabbe, Pure Mathematics; K. D. Crisp, Applied Mathematics; R. D. Dale, Design (Aero Engines); J. L. Davis (Miss), Aerodynamics; H. D. Denchfield, Applied Mathematics; A. A. Down (Sgt.), Theory of Internal Combustion Engines; G. G. Drummond, Applied Mathematics; J. R. Duncan (Miss), Strength of Aeronautical Materials and Structures; B. Eales, Applied Mathematics, Theory of Machines (tie 1st place), Design (Aero Engines); W. L. Farish, Theory of Internal Combustion Engines, Design (Aero Engines); D. J. Fermo, Applied Mathematics, Theory of Machines, Design (Aero Engines); J. A. Fuller, Applied Mathematics, Theory of Machines; J. R. D. Fuller, Applied Mathematics, Theory of Machines; O. D. Furlong, Design (Aircraft); E. Gearceoura, Applied Mathematics, Theory of Machines; J. Gilchrist, Strength of Aeronautical Materials and Structures; F. Glew, Design (Aircraft); P. M. Gray, Applied Mathematics, Theory of Machines, Design (Aero Engines); P. C. Grigg, Aircraft Materials; D. Gwynne (Miss), Strength of Aeronautical Materials and Structures; A. L. Hall, Pure Mathematics; B. A. Harding, Pure Mathematics; B. J. Hastings, Pure Mathematics; W. G. Hearle, Theory of Internal Combustion Engines (1st place); W. R. Hoskin, Design (Aero Engines); R. R. Howlett, Applied Mathematics, Theory of Machines, Design (Aero Engines); D. I. Hunt, Applied Mathematics; J. Hurry, Pure Mathematics; A. E. Jefferson, Pure Mathematics, Theory of Internal Combustion Engines, Aircraft Materials (1st place); R. F. Jelly, Design (Aircraft); A. S. Johnston, Aircraft Instruments (1st place); R. E. Lambert, Pure Mathematics, Design (Aircraft); C. D. Langley, Applied Mathematics; K. Lavanchy, Applied Mathematics; M. P. Le Lohe, Design (Aircraft); T. McCloghry, Applied Mathematics, Theory of Machines; J. McPherson, Applied Mathematics (tie 1st place), Theory of Internal Combustion Engines, Design (Aero Engines); G. Maidanik, Applied Mathematics, Theory of Internal Combustion Engines, Theory of Machines; J. G. Male, Pure Mathematics; J. M. Marshall, Design (Aero Engines); S. H. Masters, Applied Mathematics, Strength of Materials; J. C. Martin, Pure Mathematics; A. Measures, Design (Aircraft) (1st place); R. Melling, Applied Mathematics, Theory of Machines, Design (Aero Engines) (1st place); H. C. H. Merewether, Applied Mathematics (tie 1st place), Theory of Machines, Design (Aero Engines); H. H. Morgan, Applied Mathematics, Theory of Machines; D. A. O'Clarey, Applied Mathematics, Theory of Machines, Design (Aero Engines); F. A. A. Palmer, Pure Mathematics; T. Papis (F/O.), Pure Mathematics, Theory of Internal Combustion Engines, Theory of Machines; T. Pasternak, Applied

Mathematics, Theory of Machines; L. C. Pitt, Aircraft Materials; J. M. Ramsden, Pure Mathematics; G. Reed, Applied Mathematics, Theory of Internal Combustion Engines; Theory of Machines; J. H. Risdon, Design (Aero Engines); J. G. Russell, Applied Mathematics, Aerodynamics (1st place); G. P. Sandeman (Miss), Pure Mathematics; D. Scard, Design (Aircraft); H. Busen-Schmitz, Design (Aero Engines); D. M. S. Simpson, Pure Mathematics; C. E. Tharratt, Theory of Machines; A. M. Thompson, Pure Mathematics, Theory of Machines; P. J. W. Tuffs, Aerodynamics, Theory of Machines (tie 1st place), Design (Aircraft); S. A. Urry, Pure Mathematics (1st place), Strength of Aeronautical Materials and Structures, Aerodynamics; D. W. R. Vincent, Design (Aircraft); G. D. Walley, Pure Mathematics; H. L. Wallis, Applied Mathematics, Theory of Machines; P. D. Walters, Strength of Aeronautical Materials and Structures; K. R. Warren, Applied Mathematics; J. A. Webb, Navigation and its Application to Aeronautics; G. A. Willis, Applied Mathematics, Theory of Machines, Wireless Telegraphy and Telephony and their Applications to Aeronautics (1st place); D. F. Wilson, Pure Mathematics; C. C. Wood, Aircraft Materials; N. Woodwell, Applied Mathematics; A. J. Wright, Pure Mathematics; W. B. Wright, Pure Mathematics; M. A. Yusuf, Pure Mathematics.

ABROAD

The following were the successful candidates in the Associate Fellowship Examination held in December 1947:—

M. S. Balasubramanian (Madras), Theory of Internal Combustion Engines; J. G. Borman (Pretoria), Aircraft Materials; A. Cooke (Montreal), Air Transport; F. J. Dorsey (Calgary), Strength of Aeronautical Materials and Structures; F. J. Edwards (F/Sgt.) (B.A.F.O.), Applied Mathematics; A. H. S. Fernando (Bombay), Design (Aircraft); Md. Sultan Husain (Aligarh), Pure Mathematics; F. D. Jooste (Pretoria), Theory of Internal Combustion Engines; H. S. Liner (Bulawayo, S. Rhodesia), Applied Mathematics (1st place tie), Aircraft Design (1st place), Aerodynamics (1st place); H. A. R. Rao (Bangalore), Applied Mathematics; S. Krishnaswami Rao (Bangalore), Strength of Aeronautical Materials and Structures (1st place); G. D. Sadhwani (Bombay), Pure Mathematics; L. S. W. Smyth (Melbourne), Aircraft Materials; L. Townend (W/O.) (Singapore), Navigation and its Application to Aeronautics (1st place); T. V. Trinder (Pretoria), Aircraft Materials.

ACKNOWLEDGMENTS

The Council acknowledges with grateful thanks the gift of a model of a Handley Page "Halifax" made in Elektron magnesium alloy from F. A. Hughes & Co Ltd.; and back numbers of the Journal from A. Williamson, A.F.R.Ae.S.

ADDITIONS TO THE LIBRARY

Rules for Borrowing Books

Members may borrow only two books at a time.
The period of borrowing is restricted to two weeks only.
Books may be borrowed by post upon payment of registered postage one way.
Books may not be borrowed by post by members living abroad.
Books may not be borrowed and kept by students for the purpose of studying for examinations.
Any volume lost or damaged must be replaced.
All books must be signed for when borrowed.

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

B.f.102—Birds on the Wing. John Barlee. Collins, 1947.
Photographs and text showing birds (chiefly sea) in flight, landing or taking off. Excellently photographed and reproduced. Reviewed in *Journal*, February 1948.

D.b.272—Airliners and Airways of To-day. S. E. Veale. Pilot Press, 1948.
Part One: Air Liners. Part Two: Airways and Airports.

D.b.273—Air Transport and Geography. W. G. V. Balchin. Royal Geographical Society, 1947.

E.g.10—Fluid Mechanics of Turbo-Machinery. G. F. Wislicenus. McGraw Hill, 1947.
Text book dealing with the theory of centrifugal pumps and compressors, turbines, propellers and hydraulic transmissions and couplings.

EE.c.91—Aero Engines for Students, including Gas Turbines. R. A. Beaumont. Allen & Unwin, 1947.
Second (revised and enlarged) edition of a well-known text book first published in 1943.

EE.h.33—Gas Turbines and Jet Propulsion. U.S. Department of Commerce, National Bureau of Standards, 1947.
A Bibliography.

EE.h.34—Jet Propulsion Progress: the development of aircraft gas turbines. Leslie E. Neville and Nathaniel F. Silsbee. McGraw Hill, 1948.
Fundamentals of gas turbines as applied to aircraft with an outline of developments in Great Britain, the United States and Germany. Highly technical discussion avoided.

I.e.33—Tables of Hygrometric Data for Air. Institution of Heating and Ventilating Engineers, 1942.
Data and Formulæ.

L.c.30—Flight Testing: conventional and jet-propelled airplanes. Benson Hamblin. Macmillan, New York, 1946.
The Author, formerly senior flight research engineer with the Bell Aircraft Corporation, has provided a practical handbook for the flight test engineer and a useful guide to those who have to interpret flight test information.

L.d.123 *Notices to Airmen. Nos.* 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52.

N.a.90—The Science and Engineering of Nuclear Power. Clarke Goodman (Ed.). Addison-Wesley Press, 1948.
Fundamentals of Nuclear Physics, the application and experimental basis of Pile Theory and so on and a table of Precise Masses.

N.d.4—Atomic Challenge. H. A. Wallace & Others. Winchester Publications, 1947. Reviewed in *Journal,* February 1948.

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2151—*Tests on a tapered wing* (*N.A.C.A.* 23102) *with and without sweepback in the compressed air tunnel. D. H. Williams, A. F. Brown and C. J. W. Miles.*

2148—*Tests of a Griffith aerofoil in the* 12 *ft. by* 9 *ft. wind tunnel. Parts I, II, III and IV. E. J. Richards, W. S. Walker and J. R. Greening.*

2149—*Wind-tunnel tests on a* 30 *per cent. suction wing. E. J. Richards, W. S. Walker and C. R. Taylor.*

2183—*A note on compressible flow in a tube of slightly varying cross-section. G. N. Ward.*

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3873—*Atomic power in the laboratory and in the stars. R. S. Richardson.*
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1483—*Flight measurements of aerodynamic loads on the horizontal tail surface of a fighter type airplane. John S. Garvin.*
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ACTIVITIES OF THE GRADUATES AND STUDENTS SECTION

March 1948

It is regretted that owing to unforeseen circumstances the full day discussion on Safety in Civil Aviation arranged for Saturday, 3rd April 1948, has been postponed.

The Section's Annual General Meeting will be held on 21st April 1948 at the Royal Aeronautical Society. At this meeting, members elect a new committee and officers and decide the Section's activities for the coming twelve months. Members unable to attend the Annual General Meeting are reminded that they can have matters raised in their absence by writing to the Honorary Secretary.

HELICOPTER FILMS.

Three films belonging to the Bell Helicopter Co. and dealing with various aspects of helicopter operations were shown in the Library of the Society on 20th January 1948. Captain Turner, Sales Manager, and Captain Youell, Chief Test Pilot, of Irvin-Bell Helicopter Sales Ltd. were present and gave brief talks.

In "Magic Carpet," the title of the first film, something of the extreme manœuvrability of the helicopter was shown and its ability to move in any direction. The helicopter was seen operating over snowbound countryside in severe icing conditions, and the film concluded with views of helicopters under construction in the Bell Company's works.

"Utility Unlimited," the second film, demonstrated the helicopter's numerous uses, such as inspection of overhead power cables, mineral and geological surveys, crop dusting, fish breeding, rounding up cattle, and rescue work.

In the last film, "Crop Dusting," the special technique employed by the helicopter was shown, in which the under surface of the crop is dusted by means of the down-draught from the helicopter's rotors.

In the intervals between the films, Captain Turner gave a brief talk on the history and applications of the helicopter, and afterwards Captain Youell replied to a number of questions on the flying and operational characteristics of this type of aircraft.

LECTURE

The following is a brief summary of a lecture on "Some Problems of the Stability and Control of Large Aircraft" by Mr. D. J. Lyons, B.Sc.(Eng.) of Aero Flight Section, Royal Aircraft Establishment, held in the Library, 4 Hamilton Place, W.1 on 10th February 1948. In the chair, Mr. J. W. F. Housego, the Chairman of the Section.

In introducing his paper, Mr. Lyons stated that there were two broad types of stability and control problems, those dealing with large aircraft and those resulting from high Mach numbers, which were common to both large and small aircraft. He proposed to deal with the former.

Mr. Lyons defined "large aircraft" as those over 100 ft. span, with a wing loading above 30-40 lb. per square foot. The main problems on such aircraft were the difficulties of balancing the control surfaces, and his paper dealt with the four main methods which could be used to do this.

1. Fixed balance, *i.e.* horns, nose balance, geared tabs, and any kind of balance which remained unchanged with speed.
2. Spring tabs. With which a proportion of the pilot's effort went straight into the main control surface, and the remainder into the tab.
3. Servo tabs. Where all the pilot's effort went into the tab, and the tab itself drove the control surface.
4. Power operated controls.

1. Fixed Balance.

A curve of K_{b_2} (net rate of change of control hinge moment coefficient with control angle) *versus* span for typical control surfaces was shown, and it demonstrated that balance by this method was already difficult for an aircraft of 100 ft. span. For 130 ft. span or more, the controls had to be so closely balanced that over-balance was likely to occur as a result of manufacturing variations. Resort had therefore to be made to the alternative methods of balancing.

2. Spring Tab.

This was an aerodynamic trick balance with which the pilot, at each flight speed, received a certain fraction of the control force that he would have with the tab locked. This fraction changed with flight speed, and by suitable choice of the geometry, the aerodynamic balance of the tab, and the stiffness of the spring, the variation with speed could be controlled within fairly wide limits. This made the spring tab of considerable use in enabling controls to be manually operated on faster and larger aircraft than was previously possible, since they were now able to operate with any reasonable values of K_{b_2} desired. A curve of percentage of control hinge moment supplied by the spring *versus* aircraft span for a typical spring tab application showed how this device could cope with increasing size. Two points became immediately apparent:—

(i) with spans above 150 ft. or so, the spring did little in helping to hold the control surface against air loads.

(ii) at a certain span a negative spring would be needed.

The conclusion may be drawn, therefore, that while conventional spring tabs can be used up to wing spans of 150-200 ft., somewhere in the region of 150 ft. span the spring is becoming so weak that it might as well be deleted, and the utmost made of the resulting servo tab system.

3. Servo Tabs.

The lecturer demonstrated that servo tabs of quite small proportions could be arranged to give adequate control power for aircraft up to 300 ft. span without any difficulty. On the contrary, it might prove difficult to give the pilot sufficient "feel."

Since the main control surface was quite free, the pilot having a positive mechanical connection with the tab only, there remained a further series of problems:—

(a) ensuring adequate control during take-off and landing.

(b) ensuring adequate control during stalled conditions.

(c) avoidance of damage due to the main controls hitting the stops during taxi-ing and in flight.

(d) flutter prevention.

To each of these problems the lecturer suggested possible solutions.

4. Power Operated Controls.

Any control of any size could be operated at any speed provided enough amplification of the pilot's power was available. Measures could be taken to supply the pilot with "feel" either synthetically or by feedback. The greatest problem was the difficulty of guarding against the result of mechanical failure and "runaway" of the system. This problem could be treated in two ways:—

(i) to use a simple power system, and if failure occurred to revert to manual control of limited effectiveness, and

(ii) to so duplicate the system that complete failure of any one control was avoided.

Beyond spans of 220 ft. the first of these alternatives became impossibly difficult and they were left with (ii), which probably meant the division of the control surface into a number of independent parts.

Mr. Lyons concluded his paper with a short discussion on pilot's "feel" and the characteristics of "g" restrictors.

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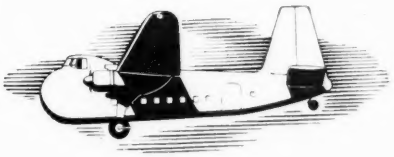

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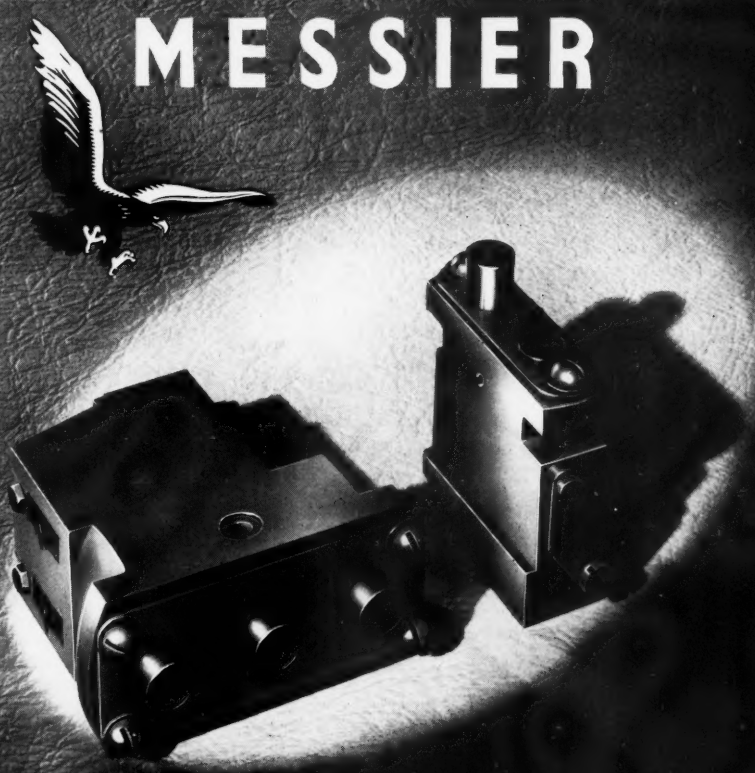

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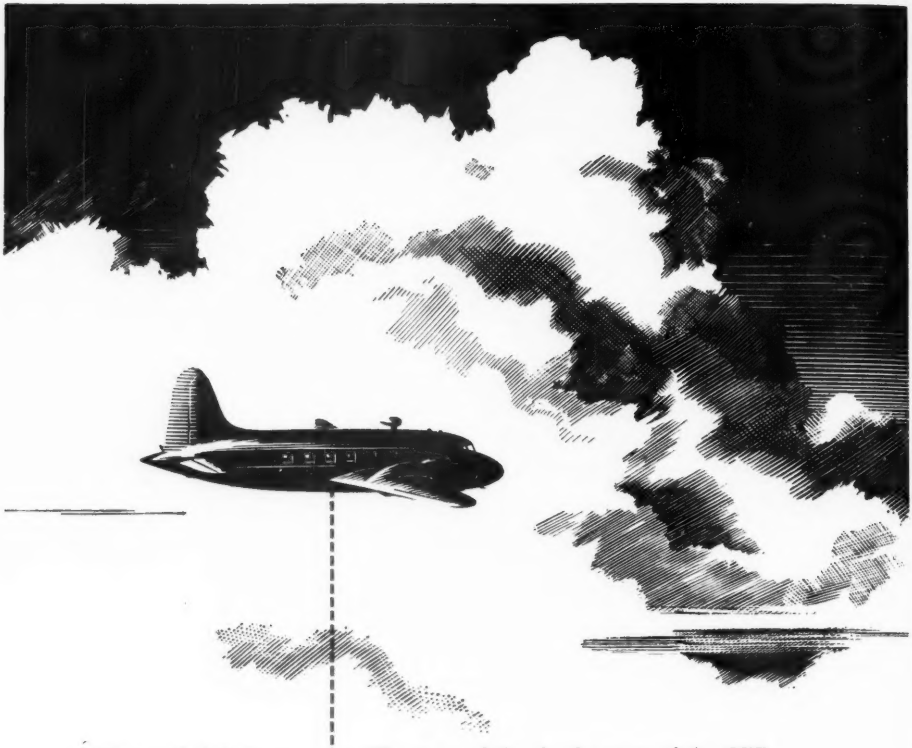

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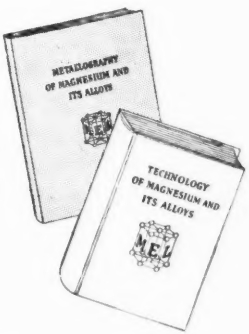

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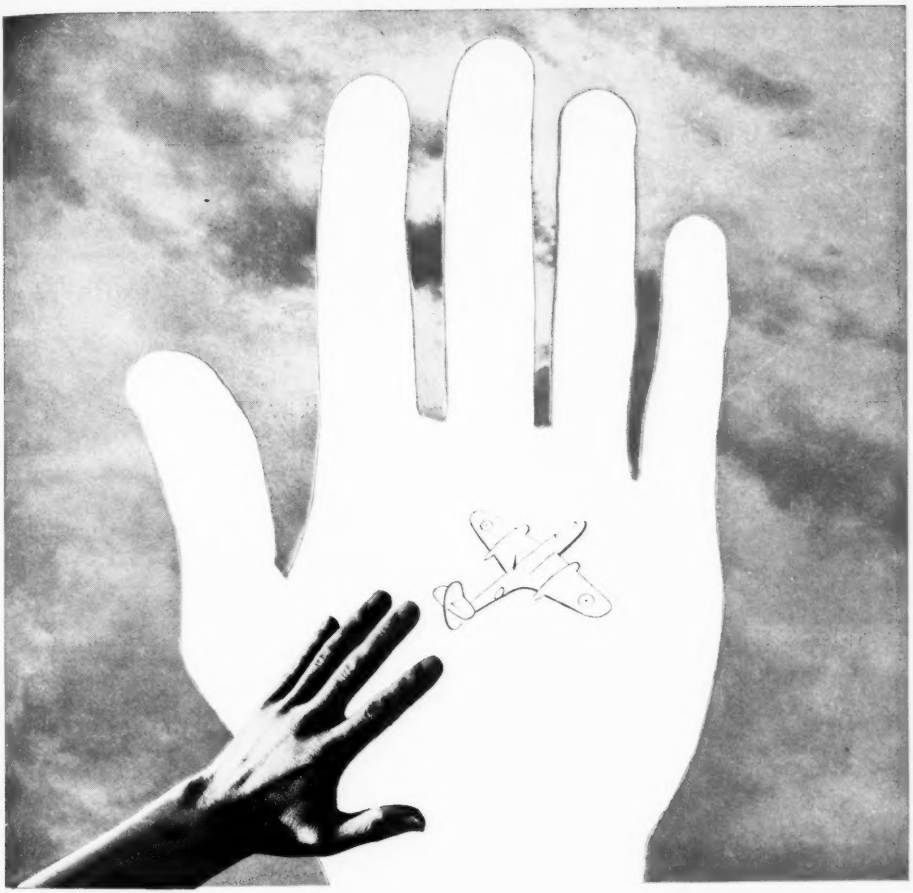

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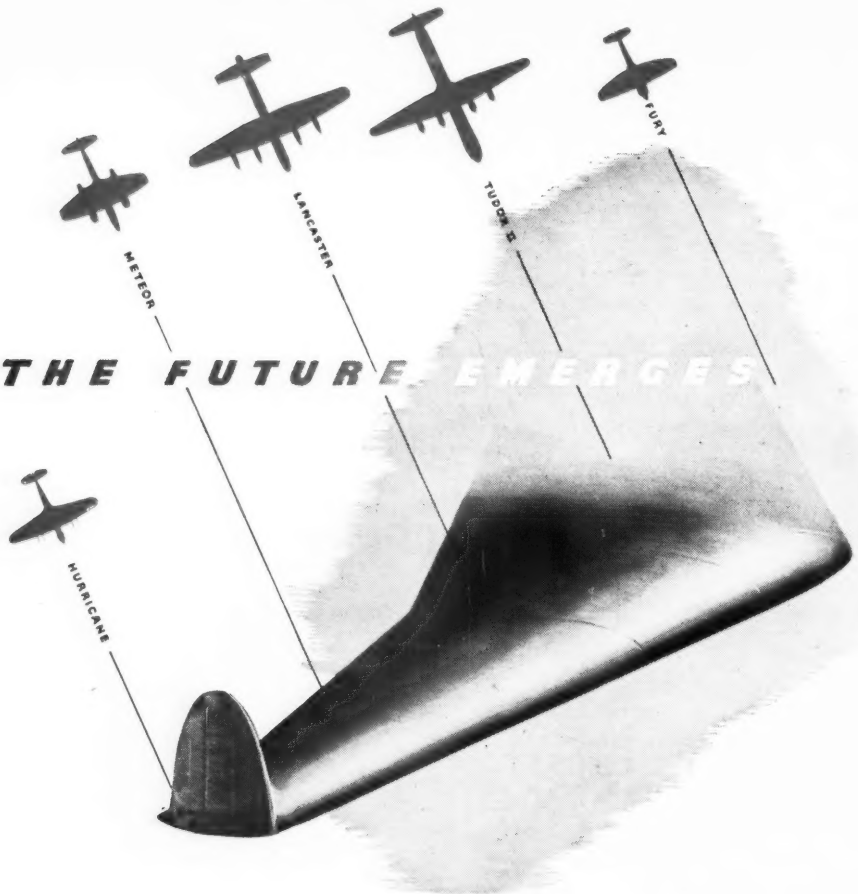

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MANUSCRIPTS

Papers must be in English, in the third person, and typed on one side of the paper only, with double spacing and wide margins. When submitted they must be in their *final form for publication*. Only typographical errors may be corrected in proofs. Titles of papers should be brief.

Where practicable, a summary of not more than 250 words should be given at the beginning of the paper, giving its scope and conclusions.

All references should be numbered in the text where they occur, and the complete list of references given at the end of the manuscript. These references will be published at the end of the text. Footnotes should be numbered consecutively. Tables should be kept as concise as possible.

ILLUSTRATIONS

Illustrations must be drawn so that they will reduce to column or two-column width, that is to $2\frac{5}{8}$ or $5\frac{1}{2}$ inches. Full page illustrations must reduce to $5\frac{1}{2}$ inches by 8 inches. All drawings must be in black ink on white paper or tracing cloth.

Lettering and figures on drawings must be in pencil only. Drawings should be posted flat or rolled.

Photographs should not be less than half plate in size and must be clear black and white glossy prints.

Every drawing and photograph should have on the back its figure number and title.

MATHEMATICS

Only very simple symbols and formulas should be typewritten. All others should be written carefully by hand in ink. Ample space for marking should be allowed above and below all equations. Greek letters should be designated by name in the margin.

The difference between capital and lower-case letters should be clearly shown; care should be taken to avoid confusion between zero (0) and the letter o, between the numeral one (1) and the letter l, between alpha and a, kappa and k, mu and u, nu and v, eta and n.

All subscripts and exponents should be clearly marked, and dots, bars, and so on, over letters should be avoided as far as possible.

Square roots of complicated expressions should be written with the exponent $\frac{1}{2}$ rather than with the sign $\sqrt{}$.

Complicated exponents and subscripts should be avoided. Any complicated expression that recurs frequently should be represented by a special symbol.

Unless an abbreviation is one recognised as standard practice, both in this and other English-speaking countries, for example, b.h.p. for brake horse power, the meaning should be given in full on its first use.

ROYAL AERONAUTICAL SOCIETY
DATA SHEETS

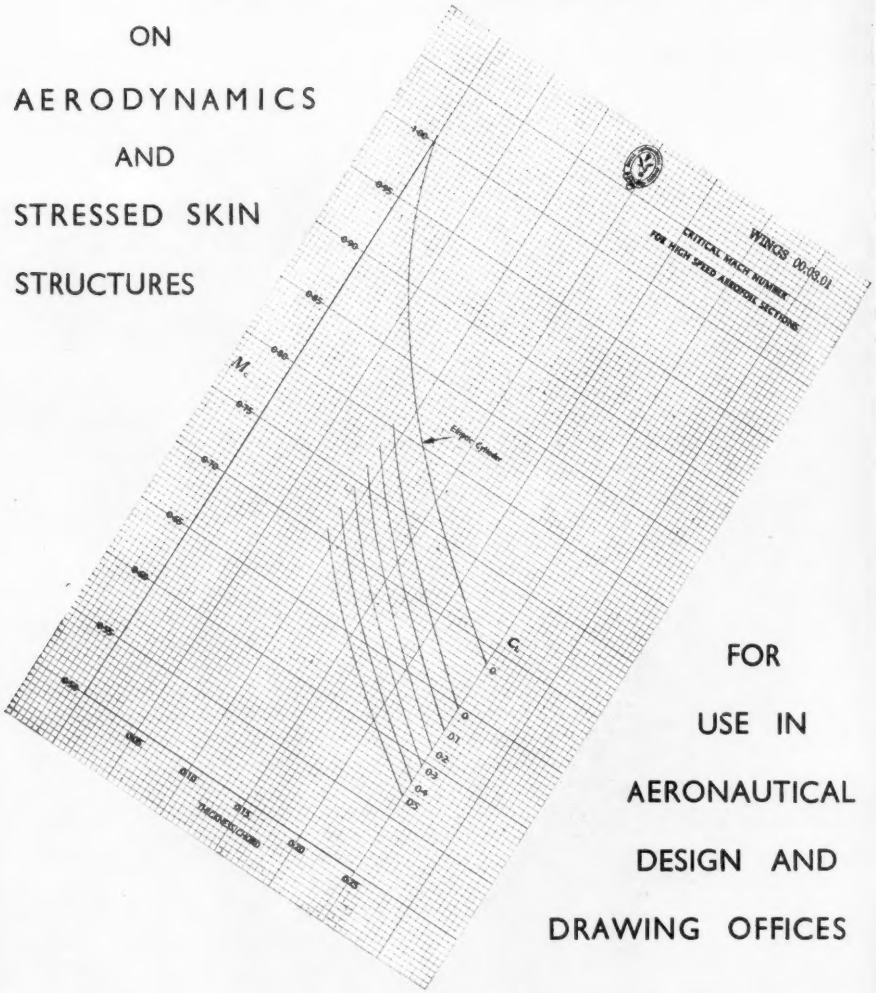
ON

AERODYNAMICS

AND

STRESSED SKIN

STRUCTURES



FOR

USE IN

AERONAUTICAL

DESIGN AND

DRAWING OFFICES

WRITE FOR FULL PARTICULARS
4 HAMILTON PLACE, LONDON, W1

THE WRIGHT BROTHERS

WILBUR

16*th April* 1867—30*th May* 1912

ORVILLE

19*th August* 1871—30*th January* 1948

ON 6th January 1916 Lord Northcliffe, seconding a vote of thanks to Mr. Griffith Brewer for his lecture on the Life and Work of Wilbur Wright, said among other things: "The fact remains, however, that after more than one hundred years of experiment with aeroplanes, these two brothers were the first people in the world who made a machine to fly, and flew it. I make that remark emphatically, because there is one point to which Mr. Griffith Brewer did not call attention, and that is the attempt that has been made to rob the Wright brothers of the credit of their invention. We have not heard much of that in England, but 'a prophet is not without honour save in his own country,' and in the United States there have been long and persistent attempts to belittle the work of Wilbur and Orville Wright. I have closely read and followed the history of the hundred years of aeroplane experiments, and I am convinced that the credit of the first flying aeroplane is due to the Wright Brothers, and from the point of practical flying to nobody else. As an Englishman I am in an independent position, and I know that these words of mine will go across the Atlantic, and I believe they will assist in stopping the spread of the insidious suggestion that the Wrights did not invent the aeroplane." (See Ref. No. 8.)

Time and time again attempts have been made to cry down the great achievement of these brothers, an achievement which has altered the face of the world.

In 1916 Mr. Griffith Brewer,* a close friend of the Wrights, a past President of the Royal Aeronautical Society, and himself a great figure in the history of aviation, fought the first round of that battle and what he said was published in the JOURNAL of the Society. It is only right that the final blow should be given again in the JOURNAL which has given so much aeronautical history of the world in the past eighty years. This account, therefore, will not be a biography of the Wright brothers, but a statement on their work. For those who wish to have fuller details of the Wright brothers themselves and indeed the Wright family, a list of references is given at the end of this paper. It need only be said that Wilbur and Orville Wright were very lucky indeed in the choice of their parents because they were two very wise people who allowed both boys to do the kind of thing they wanted to do.

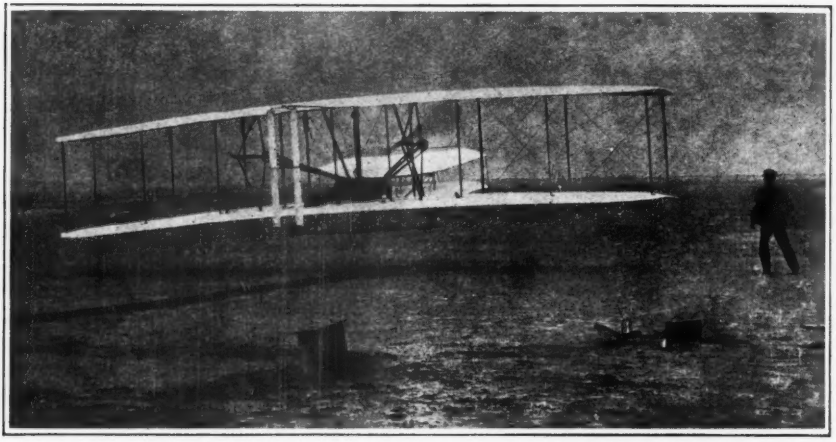
It is important to realise the kind of outlook these two men had at an early stage. They tested for themselves, and one may give a few examples of that kind of attitude of mind. They started a bicycle business in order to sell other people's bicycles and they finished by selling one of the best and cheapest bicycles on the market, of their own make. It was in 1893 that they put the first balloon tyres on any vehicle and to do this a special front fork had to be built on their bicycles and the rear frame had to be widened in order to make room for this kind of tyre. Also, in order to help him with his own calculations, Orville made his own machine for multiplying and adding and a typewriter which was a simplification of any then existing.

It was in 1895 that the brothers came across a brief note about Lilienthal's gliding experiments in Germany and they continued to read everything they could about any such experiments anywhere. It was not until 1899, however, finding how scarce any material was on aviation, that they wrote to the Smithsonian Institution at Washington asking for a list of useful books. Following the receipt of these books the two brothers began to realise the immense amount of effort which had been made in order to solve the problem.

They realised from the first that the great outstanding problem was that of stability in all its forms and particularly, that of lateral stability. They studied carefully the work of Lilienthal, of Pilcher and other people, and were of the opinion that their deaths had probably been caused by a misunderstanding of the real problem involved.

In August 1899 the brothers built an experimental biplane kite which had warping surfaces which could be controlled by cords from the ground. These experiments of control were pointing the way which was to lead to the greatest success in the history of the locomotion of mankind.

* As we go to press we have learnt with the deepest regret of the death of Griffith Brewer.—EDITOR.



The first controlled and sustained flight, 17th December 1903, Orville Wright piloting the machine; Wilbur Wright on foot.

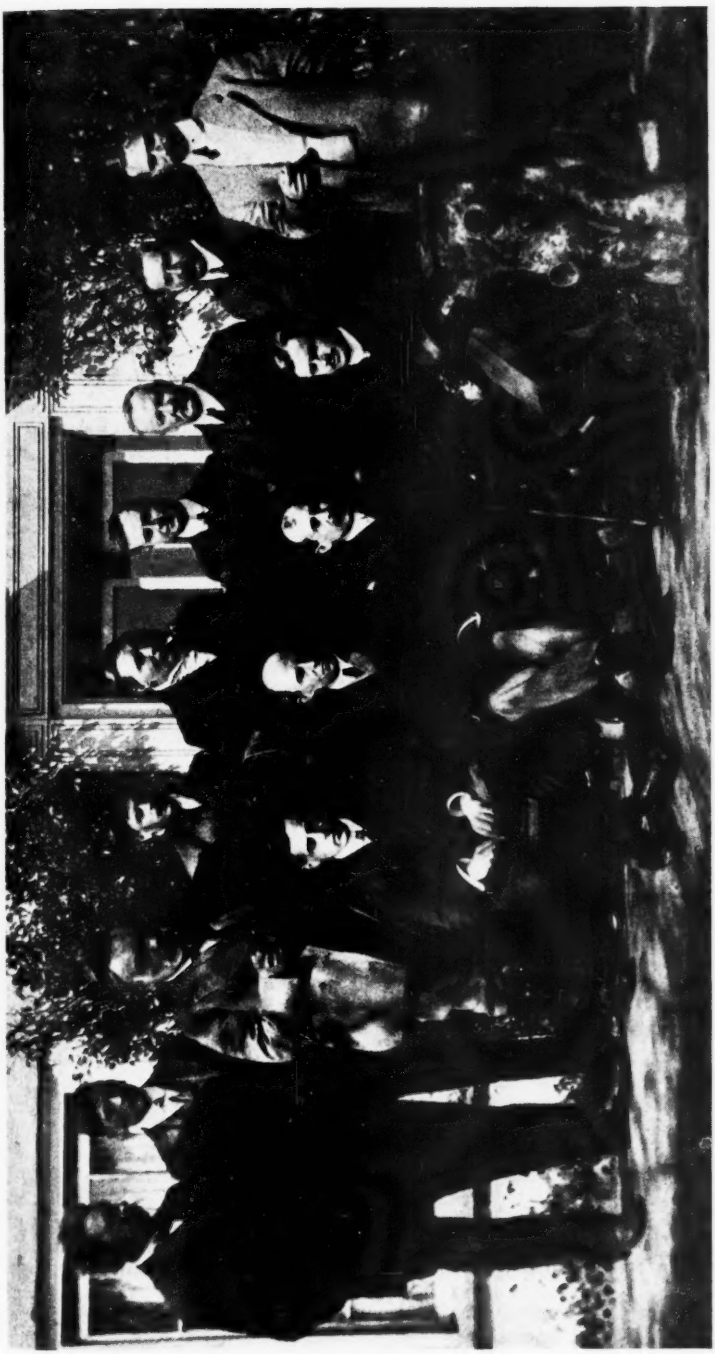
Both were men who took the greatest possible care, step by step, to verify their idea and they were determined from the beginning that before they themselves tried to fly every precaution would have been taken to make that aeroplane as safe as their ability would enable them to make it. They realised that it was necessary to find somewhere where they could get fairly steady winds and a fairly smooth surface, and following a request to the Weather Bureau at Washington and one to Octave Chanute, they picked upon Kitty Hawk.

In 1900 they completed their first glider. It weighed about 52 lb. with a total lifting area of 165 sq. ft. There was a space 18 in. wide at the centre of the lower surface of this biplane glider where the operator could lie with his feet over the rear spar. This first glider had two important features not used in previous experiments by other gliding experts. The first was the front elevator and the other was the warping of the wings. They found the control of the glider was considerably greater than they expected. Although the brothers stayed at Kitty Hawk for some months they had only been able to fly the glider as a kite with a man on board for some ten minutes in all and there had only been two minutes of actual gliding. They had learnt however the correctness of some of their ideas.

In 1901 a second glider was constructed on the same general designs with a total weight of 98 lb. and a total lifting area of 290 sq. ft., a much larger machine than anyone before had ever tried to fly. The machine was completed in July 1901 and the first glide of 315 ft. was made in 19 seconds. It was discovered that in several respects this second glider was not so good as the first one. The wings with a camber of one in twelve, as recommended by Lilienthal, Chanute and others, were not as good as the camber of one in twenty-two which the Wrights had used in 1900. They also found that the control given by the elevator and the warping of the wings was not complete and the idea occurred to them of adding a vertical fin, an idea which they were not able to put into practice until the following year. They were however, satisfied as a result of their experiments that a large machine would be as easy to control as a small one.

It was during this experiment in 1901 that the Brothers became quite clear about the movement of the centre of pressure and the knowledge of the phenomenon of the reversal of the centre of pressure was one of great importance to them in their later work. They were very disturbed by the fact that much of the information published about gliders appeared to be incorrect so that their problem of getting into the air and remaining there seemed to be so formidable that they were almost driven to the point of giving up any further attempts. Wilbur Wright, in fact, actually declared his belief that man would not fly within a thousand years!

It is to the credit of Octave Chanute, who



ENGLISH AERONAUTICAL PIONEERS AT SHELLBEACH, 1909

Back row, from left to right: T. D. F. Andrews, Oswald Short, Horace Short, Eustace Short, Frank McClean, Griffith Brewer, Frank Butler, Dr. W. J. S. Lockyer, Warwick Wright.
Front row, from left to right: J. T. C. Moore-Brabazon, Wilbur Wright, Orville Wright, Hon. C. S. Rolls.

had followed their experiments with great interest and who had encouraged them in every possible way, that he now came forward and pressed them not to give up their experiments but to go ahead as they had already done far more than any experimenters before them. Chanute was the President of the Western Society of Engineers and he persuaded Wilbur Wright to address that body at a meeting in Chicago on 18th September 1901. The title of Wilbur Wright's lecture was "Some Aeronautical Experiments." The paper was published in full in the Aeronautical JOURNAL of July-September 1916 and little comment will be made upon it here.

In the course of his address, Wilbur Wright boldly declared that the best sets of figures he could obtain on air pressures appeared to be full of errors. Afterwards he and Orville, a little scared by such a bold statement, modified it in their paper because they thought perhaps they themselves might be wrong.

Then they took the immensely important step of deciding to find out for themselves in a proper scientific way what pressures on curved surfaces were at all angles of attack likely to be met with in flight. A small wind tunnel was constructed, into one end of which they could force a current of air through a series of pigeon holes so that the flow could be straightened and made uniform. The fan for providing this current was driven by a one cylinder internal combustion engine which the Wright brothers made themselves. They provided their own measuring device and each curved surface was balanced against the pressure on a square plate, exposed at ninety degrees to the air current.

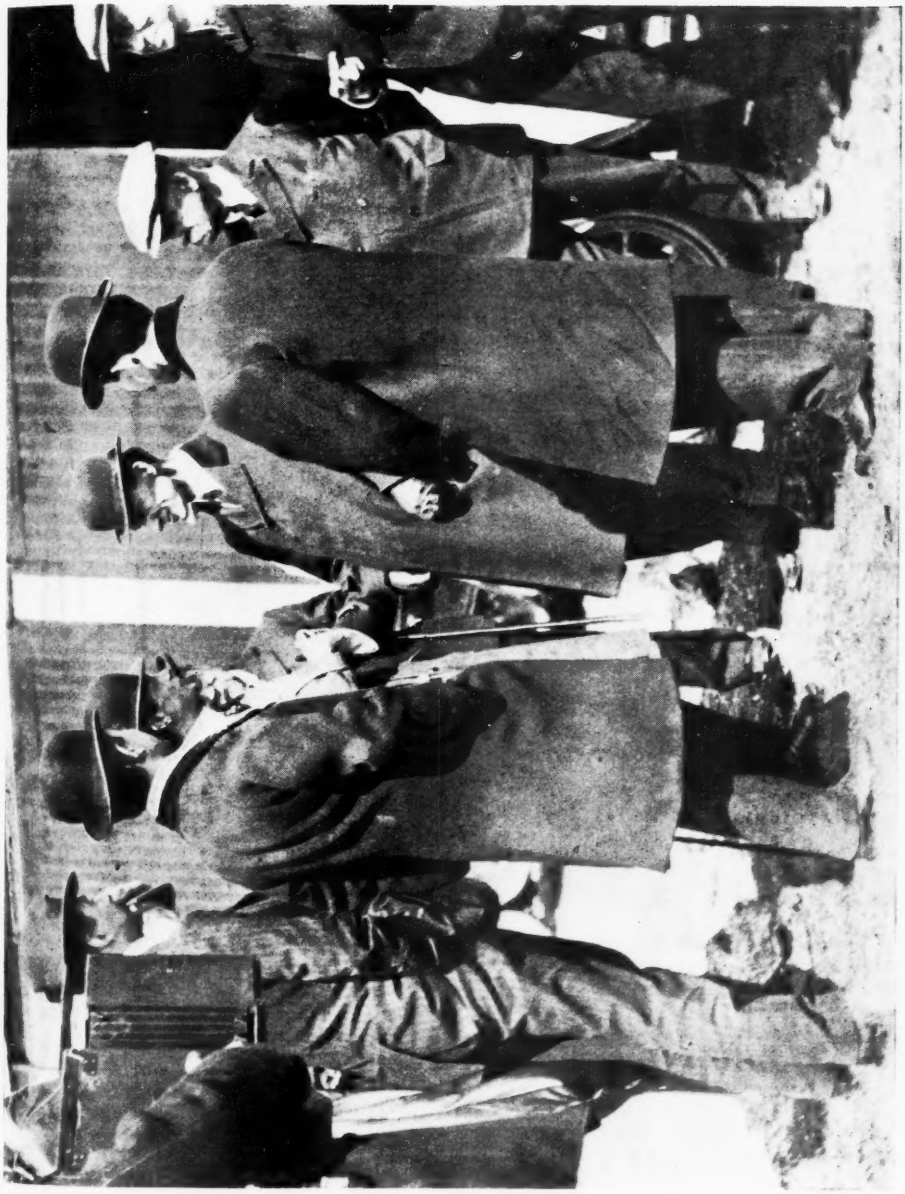
During that autumn and early winter of 1901 the Wrights tested in the wind tunnel more than two hundred types of wing surfaces. They set these model aerofoils at different angles of attack at $2\frac{1}{2}°$ intervals up to 20 and 5° intervals from there up to 40. They measured monoplane, biplane and triplane models and other types at different aspect ratios and different thicknesses. These two men were not only the men who made the first wind tunnel in the world in which miniature wings were tested, but they were the first men in the world to compile tables of figures from which it would be possible to design an aeroplane which could fly.

I quote from Mr. F. C. Kelly's book on the Wright brothers, a biography which was read and checked by Orville Wright himself, the following paragraph: "But it is doubtful if the difficulties and full value of the Wright's scientific researches within their bicycle shop are yet appreciated. The world knows they were the first to build a machine capable of sustained flight and the first actually to fly; but it is not fully aware of all the tedious, gruelling scientific laboratory work they had to do before flight was possible. Important as was the system of control with which the Wrights' name has been connected, it would not have given them success without their wind-tunnel work which enabled them to design a machine that would lift itself."

In 1902 the Wrights put their new knowledge to actual test with a new glider, their third. This was of not much greater lifting area than that of 1901 but its total lifting power was very much greater. In September and October 1902 over one thousand gliding flights were made, many of more than six hundred feet and a number of them against a thirty-six-mile-an-hour wind, something which no previous experimenter had ever dared to attempt. Some of their flights lasted more than a minute and at times they showed how it was possible to soar over a given spot without descending. During the course of these experiments they found the machine fell into a spin which could not be controlled by the warping of the wing tips. It was only after considerable thought that the brothers found the cause, and having found it they came to the conclusion that they could now build their first power-driven aeroplane.

Their first problem was to get the engine. They tried in various quarters to get a suitable one but without success, and these two brothers, with little real knowledge of internal combustion engines, settled down and built their own. In its final form the engine without magneto weighed 152 lb. and with accessories 170 lb. and developed 16 horse power on starting, dropping to a steady 12 horse power. They had calculated that they wanted 8 horse power to fly, so they were more than satisfied with their first effort.

Their next problem was that of how much thrust they could expect from the two contra-rotating propellers which were driven by a crossed chain from the engine. Both brothers naturally thought that marine engineers could give a full answer, but to their astonishment they found that they could get no figures from shipping people. If a particular steamship's propeller did not give all that was expected, all that happened was that a bigger propeller with more blades was tried, or something



Orville and Wilbur Wright, Griffith Brewer, Professor Huntingdon, J. T. C. Moore-Brabazon and others at Shellbeach, 4th May 1909.

similar until they found out which kind of propeller was best. In fact, all the work on propellers was based on experiments and observation rather than on theory. Both brothers realised that they could not afford to run any risk and they would have to get much nearer the truth.

It was many months before they were able to disentangle the intricate three-dimensional problems which were involved, but it is interesting to note that they calculated that the propellers that they had designed would produce 100 pounds of thrust at 305 revolutions a minute. These propellers were tested by actual measurement and the 100 pounds of thrust was delivered at 302 revolutions, a remarkable forecast.

Late in September the two brothers set out for Kitty Hawk and began building their machine. Just as it was ready for testing, late in November, bad weather set in but during that bad weather the Wrights contrived a mechanism which would enable them to measure automatically the duration of a flight from the time the machine started to move forward to the time it stopped, the distance travelled through the air in that time, and the number of revolutions made by the motor and the propeller.

At this point one might recall that the Wrights were accused of secretiveness. The exact opposite was the case. They were not only willing to discuss their plans with anyone, but when they were preparing for their first flight they took the trouble to write round and ask people to come along and see them make it.

On Monday, 14th December 1903 the machine was taken to Kill Devil Hill and the two tossed for who should make the first flight. The toss was won by Wilbur and Orville in his own account of that first attempt wrote afterwards: "I took a position at one of the wings, intending to help balance the machine as it ran down the track. But when the restraining wire was slipped the machine started off so quickly I could stay with it only a few feet. It was allowed to turn up too much. It climbed a few feet, stalled, and then settled to the ground near the foot of the hill 105 feet below." The machine had been 3½ seconds in the air and coming down it was damaged, but not very seriously.

Two days later all the necessary repairs were made and on 17th December 1903 Orville Wright began that flight which was to have so remarkable an effect upon the future of the world. There was a wind of 24-27 miles an hour blowing and the photograph shows the machine at the end of its track about two feet in the air. Its slow forward speed is clearly shown by the attitude of Wilbur Wright who was able to stay alongside it, although in flight. The length of the flight was equivalent to 540 feet in still air and lasted twelve seconds.

This flight was the first in the history of the world in which a machine carrying a man had raised itself by its own power into the air in full flight, had sailed forward without reduction of speed, and had finally landed at a point as high as that from which it started.

The second flight that day was made by Wilbur, who covered a distance of 615 feet. Twenty minutes later Orville Wright made the third flight, a distance of some 200 feet, and at mid-day Wilbur Wright made the fourth and last flight. Figures for this flight were 852 feet and the time of the flight 59 seconds. While they were discussing the flight afterwards a strong gust of wind caught the machine and all present rushed to try to save it. Unfortunately it was blown over and the ribs broken, the motor injured and the chain guides badly bent so that all possibility of further flights that year were brought to an end. It is worth recording that watching the most remarkable flight in the history of the world were five men, namely: John T. Daniels, W. S. Dough, A. D. Etheridge, W. C. Brinkley and John Ward.

A full account of the flight was sent to a large number of newspapers in America and during the next few days one paper published a very inaccurate account of it. During the next few weeks few papers published anything whatever about the flight and what they did publish was inaccurate, and so short as hardly to be noticed. The newspapers missed the greatest scoop of all time. The Wright brothers themselves sent out a considered statement of what had happened and even that was garbled by the papers afterwards.

At the meeting of the American Association for the Advancement of Science at St. Louis in December 1903 and January 1904 Octave Chanute in the course of an address referred to the Wrights' flights but, again, little was said about his speech in the newspapers.

There are comparatively few Englishmen alive to-day who had the opportunity of meeting Wilbur and Orville Wright, or watching them fly.

Their closest friend, undoubtedly, was Griffith Brewer who was the first Englishman

An historic lunch given to Wilbur and Orville Wright, and Miss Katherine Wright, at the Carlton Hotel, 3rd May 1909. by Mr. Frank Hedges Butler, one of the founders of the Royal Aero Club. *From left to right:* Mrs. Iltid Nicholl (née Miss Vera Butler), the Hon. C. S. Rolls, Mr. James William Butler (one of the founders and an original member of the Council of the Aeronautical Society in 1866), Mr. Orville Wright, Miss Katherine Wright, Mr. Frank Hedges Butler, Mr. Wilbur Wright, General Sir Charles Hadden, K.C.B., R.A. (representing the Army in the Aerial Navigation Commission), Captain Hugh Iltid Nicholl, Major Baden Baden-Powell, Mr. J. T. C. Moore-Brabazon (now Lord Brabazon), General John Spencer Ewart, C.B. (Military Secretary War Office), Mrs. Griffith Brewer, Professor A. K. Huntingdon, M.I.M.E., Mr. Harold Perrin (Secretary of the Aero Club), Mr. Griffith Brewer, General G. F. Ellison, C.B. (Director of Organisation, War Office), Mr. Roger W. Wallace, K.C. (Chairman of the Aero Club), Colonel Sir Edward W. Ward, K.C.V.O., K.C.B. (Permanent Under-Secretary of State, War Office) and Mr. Frank McClean (now Sir Francis McClean).

to fly in an aeroplane; the founder of the Wilbur Wright Memorial Lecture; a life-long friend of Orville Wright, whom he visited every year; a past-President of the Royal Aeronautical Society and one of the best beloved figures in aviation.

Of Wilbur Wright, Griffith Brewer wrote, following his death:—

"The present generation will never completely realise the magnitude of the loss to Aviation caused by the death of Wilbur Wright, and yet it requires but a moment's thought to recognise that his name will live until all histories are obliterated, for with his brother Orville, he accomplished the dream of ages, which men of acknowledged science had become in the habit of first attempting to accomplish, and then alleging the feat to be amongst the unattainable.

"So great was this achievement, that when Wilbur Wright came to France to show how this thing could be done, the doubters came from all over the world to see with their own eyes the achievement of the impossible.

"In August 1908 I went to Le Mans to see with my own eyes what I, like others, had hitherto doubted, and when the flying was over for the day and the machine had been put back into its shed, Mr. Wright invited me to dine with him.

"I found Wilbur Wright quite open about his work; there was no air of mystery or cloaking the achievement of flight with artificial embellishments. Just the simple story of two brothers who had always played together and worked together, and one whose health required constant out-door exercise.

"Although an American, Wilbur Wright was of English descent, and the son of a family of pioneers. One of the Wrights was one of the early settlers at Springfield, Mass., having emigrated from Kelvedon Hall, Essex, in 1636. A later ancestor moved farther West, and was one of the first to cut into the forest and found the city of Dayton, Ohio, and Bishop Wright, the father of Wilbur and Orville, has done pioneer work for the Church, whilst a further brother, evidently imbued with the same pioneer instinct, moved out West to Arkansas before his two brothers became famous."

Sir Francis McClean, that pioneer who did so much in the early days for British aviation, writes of the two brothers:—

"I first met Wilbur Wright, through the kindness of Griffith Brewer, in Paris in December 1908 and at Le Mans, in company with Roger Wallace, Professor Huntingdon and Eustace Short, he gave us flights—six minutes each and thirty feet above the ground.

"My first impressions of him were his unemotional face, his preciseness in speech and his entire lack of excitable action.

"I did not meet Orville till May 1909, when the two brothers came to England and were entertained by Hedges Butler and the Aero Club, and visited Shellbeach at Leysdown which was the precursor of Eastchurch aerodrome.

"Orville had the same preciseness as Wilbur, but was more expressive both in face and speech and often seemed to be the predominant partner, especially when business was under discussion.

"But I soon found that my first impressions were superficial and that behind their precise manner, both of them were endeavouring to assist, in every way they could, those who required help. There were exceptions—few and envious ones.

"In a short stay at Dayton in 1911, I, with Dr. W. J. Lockyer, visited their home. Wilbur was not there but Orville and Katherine and their father made us welcome with a kindliness that is beyond words. Katherine was a very real part of the brothers Wright and whenever I think of the brothers the sister is with them in the picture. The family was indeed a wonderful example of peace and unity with a simplicity that ignored the greatness that was their just due.

"One human characteristic that they both lacked was showmanship. If they had been showmen they would have been world-famous in 1903 and the wretched dispute with the Smithsonian would never have developed. If they had been showmen no one now could have found an opening for belittling them.

"But they were not showmen."

Lord Brabazon of Tara, who is the holder of No. 1 Pilot's Certificate and a former President of the Society, writes of the two brothers:—

"One of my greatest regrets is that I was never able to contact Orville Wright in recent trips to America. I never knew him as well as Wilbur, but as a couple, of course, they were the ideal partners. They both had the same approach to mechanical problems and were complementary to each other. It was Orville who did the first flight, but in skill Wilbur and Orville must have been about equal.

"Apart from their performance, which of course will go down forever, as being

historical, it was a privilege to know these two men, because they were everything that we in this country like about great men. They were retiring, shy, yet once you knew them, delightful companions with a background of real knowledge based upon experience.

"We of the older brigade have lost in Orville Wright a connection with the birth of flight, which is a tragedy. But there is also the human side, which is something we shall never forget—the privilege of having known personally these two great men, the last of whom has now passed."

Sir Roy Fedden writes:—

"The passing of Orville Wright in America recently, closes an early but vital chapter in the history of aviation. Despite some tendency to minimise their work, there is no question as to the profound importance of the Wright brothers' efforts.

"In 1938 when President of the Society and while in the U.S.A. to attend the S.A.E. Summer Conference at White Sulphur Springs, I had the privilege of being invited to visit Mr. Orville Wright at his home on the outskirts of Dayton, Ohio. I well remember keeping this appointment with a colleague one brilliantly fine Sunday afternoon in June.

"We had a most cordial reception and sat in his shady cool garden and talked for some considerable time.

"Mr. Orville Wright was extraordinarily well informed as to what was going on in current aviation, both in his country and ours. He asked a number of questions on our rearmament programme and talked about several types of British military machines.

"He was also well versed in American developments of that date.

"He showed us some relics of the Wright brothers' earlier flights and we came away feeling that here was a most charming, dignified American pioneer, who in spite of his retirement was in fact closely in touch with all that was going on in the quickly expanding outside world of aeronautics."

Following the obituary of Orville Wright published in *The Times* of 2nd February, 1948, the President of the Society, Dr. H. Roxbee Cox, wrote:—

"The aeronautical community has learned with sorrow of the death of Orville Wright. His name, with that of his brother, Wilbur, will for ever be honoured by aeronautical men. In your obituary notice you seek to place the Wrights' work in relation to that of their predecessors, contemporaries, and successors among the pioneers of aviation. But however significant the work of those others, the achievement of the Wrights was of a different order of magnitude. These were the first men to fly in a heavier-than-air machine—a machine entirely of their own design and construction. Aviation has and can have no achievement to match this. In the Royal Aeronautical Society we have many associations with the Wrights. Their great pioneer work was recognised by the award to them of the Society's gold medal—the highest honour it can confer—in 1909. When Wilbur Wright died in 1912 the Wilbur Wright Memorial Lecture was instituted, and since 1913, when Sir Horace Darwin gave the first, the lecture has been given annually.

"Orville Wright, like his brother, had the outlook of the engineering scientist. He knew the need and the value of experiment and research. In those far-off days before the first flights he had painstakingly investigated the characteristics of aerofoils by wind tunnel and other methods which were precursors of modern experimental techniques, just as the Wright machine itself was the forerunner of the modern aeroplane. In his later years he worked on a variety of investigations unconnected with aeronautics, but his interest in aviation never waned. His home was near to Wright Field, the great U.S.A. Army Air Force Experimental Station, where he was frequently an honoured visitor. I had the privilege of visiting him in his laboratory at Dayton just over two years ago. He was at the time 74 years old, extremely active, and youthful in appearance. His talk was vivacious and ranged from stocks and currency to aviation and mechanics. Some of his views on these things illustrated by their lack of convention and by the emphasis of their presentation the originality and determination which define the pioneer."

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THE ROYAL AERONAUTICAL SOCIETY

The 744th Lecture read before the Society, at a joint meeting with the Institute of Fuel—on Thursday, 15th January 1948 at the Institution of Civil Engineers, Great George Street, London, S.W.1. In the Chair, the President, Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S.

GAS TURBINE ACCESSORY SYSTEMS

by

O. N. LAWRENCE, M.A., A.M.I.Mech.E., A.F.R.Ae.S.

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1. INTRODUCTION.

THE title of this paper, "Gas Turbine Accessory Systems," covers a wide field, and one which is changing all the time. I have known many experimental units devised to perform a certain job, which were discarded almost as soon as they were made for some more up-to-date component and then, after a lapse of months or years, the original units have been dragged out from under the bench or from a museum of relics and pressed into service again with satisfactory results.

Accordingly, I have chosen to deal more with an outline of the problems facing the Accessory Engineer and the requirements he must fulfil, than with a description of the actual components adopted, or their development. The components will change, but the principles do not change much, but only alter in the emphasis placed on each. In this broad review of the problems I must cover questions which have formed part of the subject matter of papers read by my chief, Dr. Watson, before the Mechanical Engineers, and by him and my colleague, Dr. Clarke before the Institute of Fuel.

The paper begins with a statement of the requirements of a fuel system for these engines. A summary of engine types and their various characteristics follows. A brief description of the principles of control, and the way they can be applied to units, completes the first half of the paper. The second half relates to the problems connected with starting and the different systems that can be used, including cartridge starting.

2. REQUIREMENTS OF A FUEL SYSTEM.

The fuel system of gas turbine engines is required to perform a number of different functions, and it is helpful in any general consideration of the matter first to formulate the requirements which need to be satisfied. These are stated broadly below:—

(a) The fuel must be provided to the engine in a suitable form for combustion. This, in most present engines, implies atomising it first, although in time to come vaporisation schemes may come into more general use.

(b) The pilot must have complete control of the engine at all times. In present-day jet engines, control of the engine is exercised solely through the fuel system. One can liken the jet engine to an unsupercharged engine with a fixed pitch propeller. There is only one lever, controlling the fuel supply, about which to bother.

With variable pitch airscrew engines the problems of control are shared with the airscrew pitch controlling mechanism, just as they are on the ordinary piston engine. Jet engines, as used by the Germans with variable area jet nozzles, also need two controls—that of the jet nozzle in addition to that of the fuel.

In this question of "complete control" of the engine certain operational requirements must be taken into account. Rapid increases of power must be obtainable to cater for the case of a "baulked landing" and the avoidance of

excessive windmilling drag from an airscrew on sudden decelleration is also of importance. Extinction of the flame at altitude on rapid acceleration or under idling conditions must not be allowed to occur and blower stall, or surge, where this cannot be kept within limits by the general design of the engine, may require consideration.

(c) The fuel system should prevent the engine being damaged under any normal conditions of operation or as a result of careless or inept handling. This implies the provision of over-riding controls to limit the maximum speeds and temperatures to a safe value, where this is not an inherent feature of the control system.

(d) For the convenience of the pilot, a single lever control device is desirable on those engines which require both the propeller pitch and the fuel supply to be set. This must co-ordinate the two settings in such a way that the engine is working at its optimum conditions at the different times, *i.e.* full power, economical cruise, and so on.

(e) Starting conditions must be catered for on the ground and also while flying at altitude. The reason for the latter is either to remedy a case of inadvertent flame extinction (perhaps through draining a fuel tank dry) or cases may arise on multi-engined aircraft, where it is more economical to stop one engine and run full power on the others, rather than to operate at medium power on all engines.

To appreciate what these requirements really mean it is necessary to consider in brief the various types of engines, their performance characteristics and how these are affected by changes in altitude or general atmospheric conditions. Many papers have already been given by eminent authorities dealing with this subject of engine design and performance in full detail; obviously it is of vast scope and absolutely fundamental importance and is consequently somewhat controversial. But here we are concerned merely in assessing the broad generalities.

3. TYPES OF ENGINES.

There are four main categories of engine from our standpoint: the jet, the single shaft or "compressor turbine" airscrew, the multi-shaft or "work turbine" airscrew and the heat exchange engine.

(*a*) *Jet engines.*

These are the simplest. Air is compressed through the blower, heated, partially expanded through the turbine which drives the blower, the final expansion taking place in the jet nozzle, imparting to the gases the high velocity which results in the jet reaction.

(*b*) *Single shaft or "compressor turbine" engines.*

In this case full expansion takes place across the turbine, and the extra h.p. developed is passed through reduction gearing to the airscrews.

(*c*) *Twin shaft or "work turbine" engines.*

These have the airscrew driven by a separate turbine. They can be most easily visualised by thinking of them as jet engines, with a fan at the end of the jet pipe to convert the kinetic energy of the jet into mechanical power, which is then delivered to the airscrew. It follows that no matter what happens to the airscrew pitch, and therefore the r.p.m. of the airscrew shaft, the compressor and compressor turbine part will run on virtually unaffected.

In a modified form of engine, a degree of compression may be undertaken by a secondary blower on the airscrew-work turbine shaft; the engine characteristics will then be somewhat changed but from the standpoint of the control system, the engine can still be classified as a work turbine engine.

(*d*) *Heat exchanger engines.*

There is little benefit in employing a heat exchanger on a jet engine, so that such engines will all be airscrew engines. The heat exchanger is used to abstract heat from the exhaust and supply it to the compressed air from the blower before its delivery to the combustion chamber. The amount of fuel required by the engine is obviously modified by the quantity of heat received by the air from the heat exchanger.

4. ENGINE CHARACTERISTICS.

All types of these engines have basically similar characteristics. If we consider the jet engine first, we can elaborate later the differences on the other types.

Fuel consumption is the most important characteristic in considering accessory sys-

tems. Since this varies in accordance with altitude, aircraft speed, atmospheric temperature and engine speed, it is necessary to resort to non-dimensional curves. Fig. 1 indicates the usual form of such non-dimensional curves, but Fig. 2 shows the same curve replotted in a form which is more convenient for the consideration of control systems. The symbols P and T signify pressure and temperature, and suffixes 0 and 1 refer to ambient atmospheric and ram conditions respectively. V in the parameters refer to aircraft speed; these parameters are parameters of aircraft Mach number and can be referred to alternatively as pressure ratios P_1/P_0. The symbol F refers to the fuel flow, A to the air mass flow, and N to the r.p.m. The suffix 2 is used for conditions appertaining to the blower delivery, and 3 to those after the combustion chamber.

The drop in fuel consumption at high aircraft speeds and low r.p.m. is noteworthy; pursuing this to the limit, the engine actually windmills under flight conditions at a reasonable r.p.m. without any fuel being supplied.

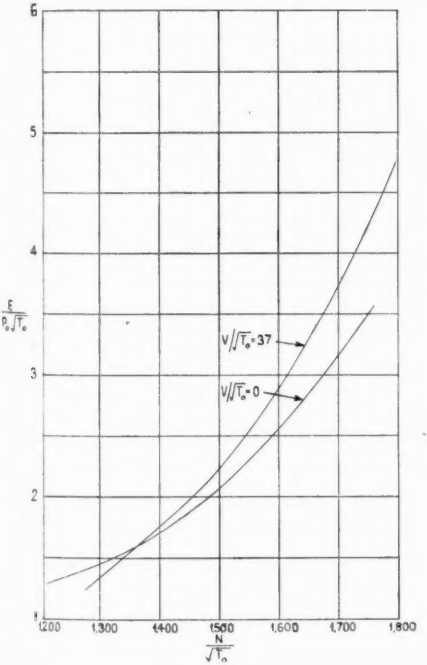

Fig. 1.

Fuel consumption curve for a jet engine non-dimensional plot using ambient air conditions.

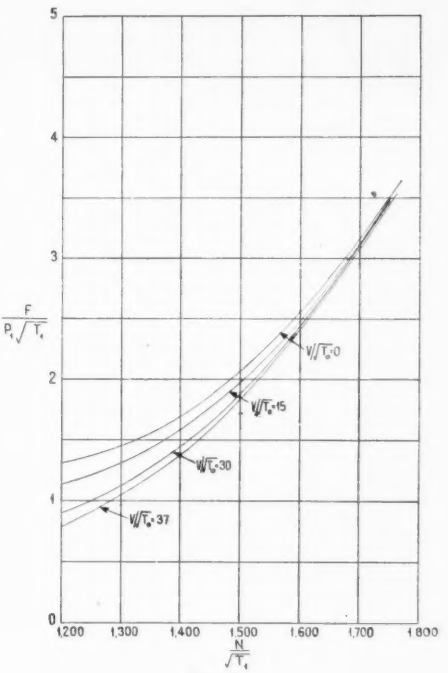

Fig. 2.

Fuel consumption curve for a jet engine non-dimensional plot using ram air conditions.

From such an analysis, it is possible to calculate the theoretical fuel consumptions under maximum conditions (full throttle top aircraft speed and cold atmospheric conditions) and the minimum conditions at altitude, say 50,000 feet. Expressed as a ratio, the figure works out to be 75:1. Because of the reduced combustion efficiencies at altitude, the reasons for, and measurements of which, are recorded in a paper before the Institute of Fuel last year,[1] this figure is not attained, the actual ratio being nearer 30:1. Further investigations in this country have shown that improved atomisation will improve the combustion efficiency markedly (although not up to 100 per cent.), and it is probable that fuel ranges of considerably above 30:1 will have to be dealt with in the near future.

It is worth recording that the idling consumption at extreme altitude will be affected by the power absorbed by bearing friction and in driving accessories, in addition to being dependent on the "windmilling" effect due to aircraft speed.

The range of engine speeds over which control is necessary is of importance in assessing the ease, or rather difficulty, in providing a governor control. The piston engine operates over a speed range of eight or nine to one (although not with the governor, *i.e.* C.S.U. control operative all the time). The modern jet engine operates over a speed range of approximately five to one, although a lower idling speed would be advantageous. The bottom limit to idling speed is set by the sluggish acceleration at low speeds and the high jet pipe temperatures encountered.

The advantage of a low idling r.p.m. lies in the reduction in thrust under idling conditions. The effect of even a small remnant of thrust is the more noticeable because of the extreme cleanness of the engine installation and aircraft generally. On a propeller engine, higher idling r.p.m. are usable by using very fine pitch. Alternatively, variation of the jet engine's propulsion nozzle would achieve the same result.

This range of 5:1 in speed, coupled with the requirements of negligible governor "rate" and "overswing" at the top r.p.m., makes the specification for a governor system difficult to fulfil.

A point of interest is the difference between the power absorption characteristics of a jet and a propeller. Wih a propeller operating in constant pitch, the h.p. absorbed varies as the cube of r.p.m. With a jet, it may be shown theoretically that the kinetic energy of the jet varies as something over the fifth power of the r.p.m. over the cruising range; this is borne out by test figures, the index actually being 6. The thrust varies as r.p.m. to the power of 3.3. These factors are of interest in comparing the control of jet engines with that of propeller turbines.

The range of conditions that have to be catered for with propeller turbine engines, in general will be similar to those for jet engines, but not so great. This is because the airscrew engine will normally be designed to operate at a lower altitude than its jet counterpart.

The heat exchanger engine will normally require to operate with a greater range of fuel consumption, because the economy from the heat exchanger will be greatest at low r.p.m., thus increasing the range of flow between full throttle and idling consumption.

5. ATOMISATION.

Others [1, 2] have dealt fully with this question, so that a detailed treatment is not required here.

This matter of providing atomised fuel has a fundamental influence on the general design of the fuel system, so it is as well to state the problem. Highly atomised fuel is required at all times but more particularly under idling conditions at altitude when the fuel flow is least. The range of fuel flow required is as we have seen, at least 30 : 1. The fuel will normally be supplied to the engine through a number of burners distributed around the engine's periphery and it is vital that the flow from each shall be the same within close tolerances. Undue complexity of the burner or of the control system which goes with it, is a disadvantage.

There is nothing new in the problem of atomising fuel for combustion; it is used in the firing of boilers and any number of other places. One of the most common methods is to induce a swirl into the fuel and use the resulting centrifugal forces to promote atomisation. The "Monarch" burner is a well-known example in industry. We know this type as Simplex burners. The higher performances required for these aircraft applications has led to a great deal of research, in the course of which refinements to the general design have been discovered which improve the burner performance appreciably. The spray from these burners emerges in the form of a hollow cone; this is suitable for use on multi-combustion chambers of circular cross section.

The Simplex burner is not so suitable, perhaps, for annular chambers, when radically different designs of burner may be adopted, but finality in this has not been reached.

By their very nature these Simplex burners are "square law" burners, *i.e.* the pressure drop variation for a flow range of 30:1 is 900:1. Really satisfactory atomisation is not obtained at pressures below perhaps 50 lb./sq. in. although, for want of better, pressures of down to 4 or 5 lb./sq. in. have been, and are being, used. Combustion can just be maintained but at a low efficiency.

Whatever the design of burner adopted, it is probable that the use of moderately high pressures will provide useful benefits in performance.

The atomisation obtained from a burner is basically a function of the Reynolds number; that is the lower the viscosity of the fuel the better the atomisation. The fuel viscosity may be intrinsically low, as in the case of petrol, or artificially lowered by pre-

heating (as adopted to some extent on boilers and so on). The effect of a very low viscosity is to give adequate atomisation at low pressures. Care, in this case, will still need to be taken since the disposition of the burners round the engine at different levels will cause more fuel to flow to the lower cans than the upper ones.

The capacities of Simplex burners are normally measured in flow numbers. This is defined as the flow of paraffin in gals./hour which the burner will pass divided by the square root of the fuel pressure.

Various schemes have been adopted to overcome the difficulties of the square law pressure relationship. Many of them depend on varying the area of the tangential entry passages to the swirl chambers, which will vary the flow number appreciably, although it also modifies the cone angle of the issuing spray. This modification of entry area may be effected mechanically by a plunger moving back and uncovering more of the slots; by dividing the total area into two parts, one small and one large, and arranging for the small area only to be in operation at low flows and bringing the large part progressively into operation at high flows; and lastly by hydraulically filling part of the entry slots and arranging for the extra fuel which is "filling" up the slots to be spilt back to tank instead of being sprayed. Fig. 3 shows the second, or Duplex type.

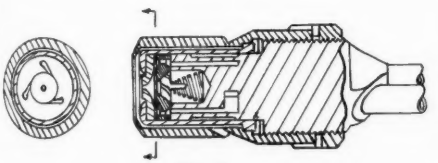

Fig. 3.
Duplex burner assembly.

The Duplex burner is susceptible to hydraulic instability unless very carefully designed and made. One method of overcoming this trouble is to use the so-called flow distributor, Fig. 4. Each burner is connected to this distributor by a separate pipe; in the distributor itself there are separate metering orifices which are each uncovered by the motion of a common control piston. The pressure drops across these metering orifices at low flows are made sufficient to swamp all other effects so equalising the flows, while as the fuel pressure increases the piston moves back and opens the orifices fully, so that at full flows the pressure drops incurred across the unit are very slight and equalisation of the fuel flows is dependent on the matching of the burners themselves. This unit could also be used to overcome the manifold head effects on Simplex burners if desired.

Spill burners would appear to be the ideal choice, but for some drawbacks. First, recovery pressures. It is necessary to pipe away the spilt fuel from the burners and in the case of certain designs the spill pressures are not very different from the pressures into which the burners are discharging, *i.e.* combustion chamber pressure. But it is not only necessary to pipe this spill away, but also to equalise the quantity spilled from each burner if equal characteristics are to result. With the constructions of burner, in which very low spill pressures do not occur, it is a fundamental consequence that the atomisation performance of the burner suffers severely. Added to this is the difficulty of designing a control to operate on the difference between the fuel supplied to the burner and the fuel taken away as representing the actual fuel sprayed into the engine. This latter can be circumvented, but it adds to the inconvenience and general disadvantages of spill burners.

One particular method of controlling these burners is to have a re-circulating pump or injector to raise the pressure in the spill and return it to the main fuel supply line. The flow delivered to the engine is equal to the fuel supplied by the main pumps in this case. Regulation of the engine may be by a flow control acting on this. The re-circulation of equal quantities of fuel from each burner may be ensured by fitting individual positive delivery pumps in each spill line and drive these from a common shaft. Fuel pressure acting on a turbine may be employed as the driving medium.

Very fine atomisation can be achieved by the use of air atomisation. The objection to this lies mainly in the difficulty in the provision of air. A separate air compressor is required to deliver air to the burners at a higher air pressure than exists in the combustion chamber. The pressure required is 5 lb./sq. in. gauge under idling conditions, but the quantity of air, some 2 to 3 lb. of air per gallon of fuel burnt, is quite big and at speeds above idling some higher pressures are required.

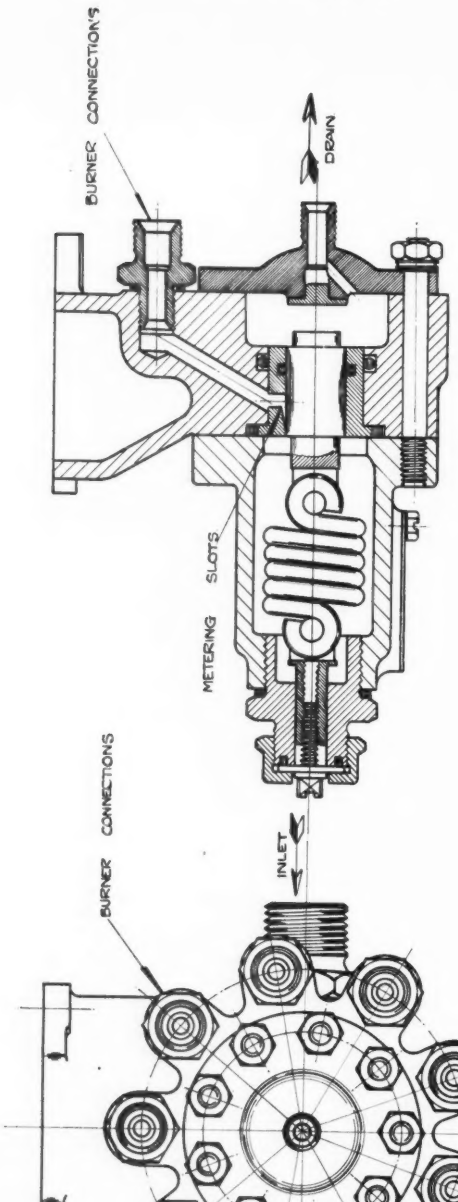

Fig. 4.
Flow distributor.

A practical point to be borne in mind with any design of burners is that since the burners will normally contain small holes, it is almost essential to fit individual filters in each burner, as near the final atomiser as possible to protect it from any form of dirt. This dirt may get in when pipe connections are broken or new pipes are fitted; it may arise from corrosion of the piping.

6. PRINCIPLES OF CONTROL.

All aircraft gas turbine engines have to be operated near the top limits of speed and temperature permissible, if a satisfactory performance is to be obtained. In a recent paper to the Royal Aeronautical Society, Sir William Griffiths* exhibited curves showing the effect of both temperature and speed on the creep strength of the turbine blades, for instance. Both variables have similar effects, that is a sudden changeover point, above which the rate of creep is greatly increased. It is the temperature effect which would appear to be the most critical of the two. It is accordingly preferable, from an engine life point of view, to reduce engine temperature rather than r.p.m.

Even short exposures to high temperatures are believed to be bad for the blade materials. A point of argument that arises is, how quickly does the blade metal follow the change of gas temperature.

These considerations must be taken into account in arriving at the choice of fuel system and its method of operation.

6.1. CONTROL OF JET ENGINE.

It was stated that control of the jet engine was affected purely by regulating the fuel supply. It may be asked, why not give the pilot direct control of the fuel supply? This has been done in the past, but the trouble is that the changes in fuel consumption with altitude are so great, that the position of the throttle valve which corresponds to idling speed at ground level, would result in the engine running at maximum speed somewhere above 30,000 feet. So as to give the pilot reasonable control, it is necessary for the control lever's position for idling and maximum speeds to remain relatively constant irrespective of altitude or any other variable. The tendency now is to insist that this should be adhered to, rigidly, so that pilots may be spared the trouble of periodically checking that their engine is operating at, for instance, the correct climbing r.p.m.

The barometric device, then, is a method of keeping this lever movement approximately correct for all altitudes.

As we saw from Fig. 2, the fuel consumption characteristic of the jet engine can be expressed as:

$$F/P_1\sqrt{T_1}=f\left(\frac{N}{\sqrt{T_1}}\right)\phi\left(\frac{V}{\sqrt{T_0}}\right)$$

$$\text{or } F/P_1=\sqrt{T_1}f\left(\frac{N}{\sqrt{T_1}}\right)\phi\left(\frac{V}{\sqrt{T_0}}\right)$$

where f and ϕ are functional signs.

If we neglect $\phi\left(\frac{V}{\sqrt{T_0}}\right)$, the aircraft speed parameter, we see that atmospheric temperature appears in both the remaining terms, but in an opposite sense. It is not surprising that the system of control first successfully used and the most widely adopted to this day, should be a barometric one relating fuel flow to barometric pressure. Unfortunately, we cannot merely ignore the functional sign f and cancel the $\sqrt{T_1}$. The temperature still has a material effect on the fuel consumption of the engine. Some compensation for change in temperature with altitude can be arranged by faking the barometric correction from a true F/P_1 characteristic, but departure of the atmospheric temperatures from the I.C.A.N. laws at different times, and so on, are sufficiently great to affect matters considerably.

It is worth emphasising here that in any barometric control, it is most important to use ram pressure P_1 and not the ambient pressure P_0. This is easily seen from a comparison of Figs. 1 and 2 remembering that the barometrics are primarily calibrated to maintain constant conditions at the maximum or at cruising r.p.m.

Accepting such a system as our control system for the moment, and considering what else is required, we see that to satisfy paragraph (c) of the requirements, we must provide an overspeed governor; in point of fact this is usually employed as the maximum full throttle setting, the barometric device being set to control at a slightly higher speed, so as to cater for very cold conditions, when the engine's fuel consumption is increased and it would not otherwise reach its maximum speed.

* The Problem of High Temperature Alloys for Gas Turbines, Sir William T. Griffiths, Journal of the Royal Aeronautical Society, Vol. 52, No. 445.

Maximum temperatures are not normally controlled. With the atmospheric temperature variations usually experienced, they remain substantially constant with r.p.m., although slight changes will occur with altitude. These are due both to the higher pressure ratios obtained at the lower atmospheric temperature being accompanied by lower efficiencies and also to the changes in Reynolds number on the blower. Temperatures also change with deterioration of the engine, so that benefits would accrue from the fitment of temperature control.

It is clear that the fuel supply to the engine can be controlled to maintain other engine functions at a desired setting—such functions as r.p.m. or temperature, for instance. The use of either of these might do away with the necessity for providing one of the separate safety over-rides, which are otherwise desirable (although, as mentioned, present jet engines have not yet been fitted with temperature over-rides).

The use of r.p.m. for control would have many advantages for instance, the pilot naturally measures the engine performance according to a dial—and a tachometer is an instrument he is accustomed to using. The main objections to adopting this system, at present, are technical. It is difficult to obtain satisfactory governing over the wide speed range required on the jet engine. Any such governor must have a very low "rate," particularly at the maximum speed end, so as to protect the engine from damage. This is because altitude reduces the engine fuel consumption for a given speed, and hence the governor has to operate its valve further to reduce the fuel supply to the required value for the steady speed. Any "rate" will result in the engine speed rising with altitude, and this must be kept to the minimum; in fact because of the rise of temperature at constant r.p.m. a negative "rate" governor would be desirable if this could be stabilised.

But this is not all; some form of acceleration control is necessary in this case. Any acceleration, even of a small amount, will result in the governor attempting to supply the engine with full fuel until the speed is reached—this is a natural consequence of its small rate and must be controlled by an acceleration control of some sort; the simplest solution, a dashpot device on the control lever would really be satisfactory, and have the right response at one altitude only, but in any case it is not fancied for other reasons.

Temperature control is from many aspects the ideal function to choose, being even better than r.p.m.; but it is not the easiest to provide. For one thing control of the engine at low speeds cannot be undertaken in this way because, due to the compressor and turbine efficiencies deteriorating the temperature r.p.m. curve flattens off and control becomes impossible. Control of the engine must be taken over by a subsidiary control over this range.

Two further minor control devices may be required on certain engines, depending on their design and conditions of operating. The first is a control of idling speed. Reference has already been made to the fall-off in combustion efficiency at low r.p.m. under altitude conditions and to the effect this has on the fuel consumption. Controlling on the fuel flow, this flat curve will make speed wander difficult to avoid, even if actual engine shut down does not occur. This particularly refers to the normal run of barometric devices, which have to be set to maintain the full throttle conditions right, without taking much account of the idling conditions. The second is an acceleration control. Other systems as well as the all-speed governor suffer from over-fuelling on acceleration, although to a less extent; it is at extreme altitudes that the effect becomes severe. The result of the over-fuelling manifests itself in different ways: flame extinction may result from dousing the flame with too rich mixtures, or acceleration surges or stalling of axial blowers may result, or excessive acceleration temperatures occur. Any of these effects are best avoided, and the first two particularly might have serious consequences.

In considering the control of airscrew engines, we shall have occasion to mention the operating point on the blower characteristic curve. Such a curve shows the pressure ratio of the blower plotted as a function of the (non-dimensional) air mass flow and of the $N/\sqrt{T_1}$, Fig. 5. The blower pressure ratio is a unique curve for values of $N/\sqrt{T_1}$ with constant $V/\sqrt{T_0}$. It follows that the locus of operating points for the jet engine is a unique curve for any value of $V/\sqrt{T_0}$, although it varies with this.

6.2. Control of Propeller Turbine Engines.

(a) Twin-shaft or "work turbine" engine.

Dealing first with the twin-shaft or "work turbine" engine; this work turbine, being but

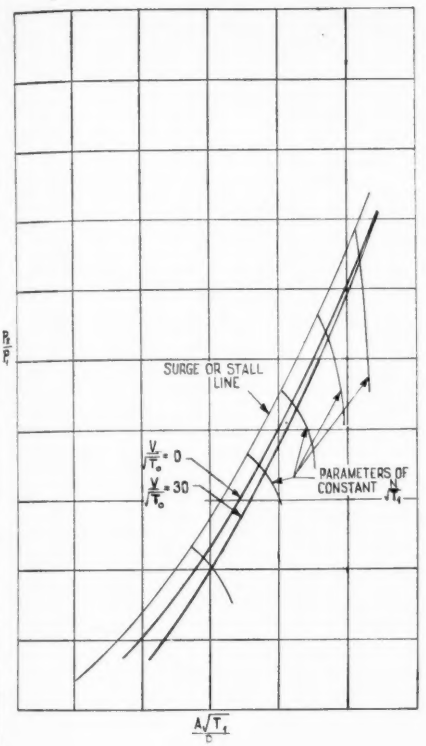

Fig. 5.
Compressor characteristic curves for a jet engine.

a fan in the jet pipe, will not affect the operation of the first half of the engine to any great extent This can then be controlled, as if it were a jet engine. The work turbine will absorb what horse power it may from the gases directed upon it, this depending in part upon the r.p.m. at which it runs. The r.p.m. is determined by the pitch of the propeller, for at any one pitch there will be a relationship between the r.p.m. and the h.p. required to drive the propeller and the h.p. produced by the turbine must mate up with this. A C.S. propeller can be used to set the pitch to control the r.p.m. to the desired value. (The analogy of a fan in the jet pipe must not be carried too far; normally there will be some slight effect of the second part of the engine on the first half.)

We have, however, got to satisfy the requirements listed under (c) and (d) above. The propeller shaft must be protected against sudden over-speeding by a device acting on the fuel supply, for the C.S. governor is notoriously not immediate in effecting changes in propeller pitch. The control of the C.S.U. and of the engine through a single control can be arranged readily by a simple inter-connection. Then the propeller r.p.m. will be set at given figures for different degrees of throttle opening. As on the jet engine, temperature limitation will be an advantage to guard against engine deterioration and changes of temperature with altitude.

It will be noted that the h.p. supplied to the propeller is set by the operation of the compressor turbine shaft. The C.S.U. therefore can be manipulated to give the best airscrew efficiency without reference to the rest of the engine. This adjustment can be undertaken at leisure, since it only affects the fuel economy and consequently the advantages of single lever control are more limited in this case than with the single shaft compressor turbine engines, being more a matter of convenience and of ensuring that the pilot does not fly with his propeller too badly adjusted. (The single lever control must be a compromise, which could be bettered by a really intelligent setting of the two controls independently.)

It is clear that another possible means of inter-connection is to make the r.p.m. of the propeller dependent on the engine r.p.m., although not being rigidly connected. For instance, the use of a gear train between the two shafts would obviously turn the engine into the equivalent of a single shaft engine (compressor turbine engine); but by adopting a floating coupling, so that the propeller pitch is modified in such a way as to keep the propeller r.p.m. a certain ratio of the compressor r.p.m., the engine from the control angle may be regarded as a two-shaft "work turbine" engine, although the characteristics under steady r.p.m. conditions would be equivalent to those of a single shaft unit. The difference between the concepts occurs under changing speed conditions, for then with this system, the compressor-turbine-shaft control sets the conditions, and the propeller pitch control must follow up as quickly as its response lets it, but it can never modify the running of the compressor-turbine shaft and therefore interfere with the running of the engine.

(*b*) *Single shaft "compressor turbine" engine.*

The single shaft or "compressor turbine"

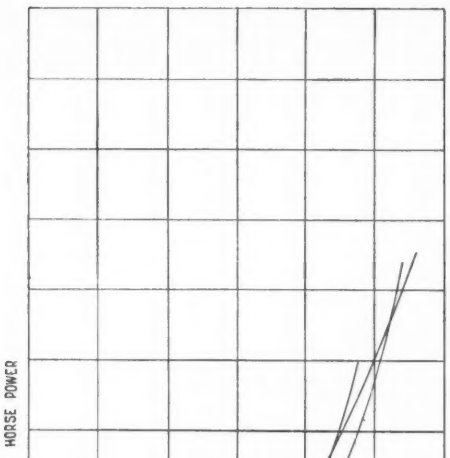

Fig. 6.

Typical power output curves from a compressor turbine type engine.

engine differs in just this way. The one turbine provides the power for both propeller and compressor, and the relative proportions in which the power is divided are decided solely by the control of the propeller pitch. Control of the fuel to the engine therefore determines largely the total power output of the turbine and the pitch, the subdivision of that power. It follows that these two factors must be very closely inter-related for satisfactory control; too fine a pitch means too low a gas temperature for any given fuel supply and too coarse, too high a temperature resulting in certain cases (apart from the deleterious effects of high temperature on the blades, and so on), in compressor stalling or surging, or even in extreme cases to a cut out of the engine. But that is considering steady running conditions. Under changing speed conditions, it is clear that the relative rates of response of the two control systems will need to be considered.

Another general point relating to these engines, which must be borne in mind from the start, is the prime necessity of using interconnected controls. The compressor being rigidly connected to the propeller, it follows that the power absorbed under windmilling conditions will be very large, and might in fact jeopardise the aircraft, if these conditions were encountered inadvertently. This might easily occur and it is necessary to guard against the possibility by inter-connection.

Looking at the problems from first principles, we see that the two devices controlling pitch and fuel respectively, may be made responsive to any two of the variables, speed (or blower pressure ratio), power (or torque), fuel supply or temperature. The choice of which quantity is used for which purpose is immaterial so far as the engine is concerned, the individual characteristics of the control devices such as response time, reliability and convenience of installation, as well as their inter-action on each other, must dictate the choice.

The use of power as a control function is not very attractive. It is, of course, the basic feature of the engine which really most affects the pilot, but it is not easy to measure and feed back as a controlling force into a unit, and in practice varies closely with the fuel consumption over the operating range. It could be utilised without too great inconvenience, to set the airscrew pitch, although it would need resetting in accordance with ram atmospheric pressure and temperature, just as the fuel flow control does.

The use of either fuel flow or power for control leaves the necessity for providing over-rides for speed and temperature. Using these two, though, would eliminate the need for over-rides The simple system of adopting a C.S. propeller and a temperature control on the fuel supply has a catch in it. Fig. 6 shows the shape of the h.p. characteristics to be expected from such engines. With the propeller in constant pitch, the jet pipe temperature from the engine remains nearly constant with r.p.m., with a tendency to rise at the lower speeds. It follows that the r.p.m. must be set by a unit with a quicker response than the temperature control, or the engine will wander and even fade out. But this means that the temperature control must have a slower response than the propeller—an unsatisfactory state of affairs.

Reference was made earlier to the difference in characteristics between jet engines

and fixed-pitch propeller engines. Since with the jet engine, the power in the jet (kinetic energy) varies as a much higher power of the r.p.m. than the cube, temperature control is quite stable.

The converse system of controlling the propeller turbine engine would seem to have much in its favour. A speed governor controlling the fuel supply can be made with a quick response. The temperature control need not respond too quickly either itself or in its effect in varying the propeller pitch. This will help in the construction of both units. Of course, this would not be so applicable to highly manœuvrable and aerobatic aircraft, for which a high rate of pitch change is desirable.

To have a quickly responsive unit to set the speed is desirable, for the power of the engine is largely controlled by the speed and, to a much less extent, by temperature. Having got the speed right, the less important trimming can take place later.

It will be seen that this system fits in well with the reasoning at the head of this section. The total turbine power is set by the control of the fuel by the governor and the subdivision of this between the compressor and the propeller, which directly affects the gas temperatures, is set by these temperatures. An alternative of equal merit would be to control the fuel by a unit responsive to flow, instead of by a governor, so long as due account of both atmospheric pressure and temperature is made.

A system largely adopted at present is the use of a C.S. propeller with a barometric device. An over-speed governor is necessary. Using this control set-up, it is necessary to incorporate some means of resetting the interconnection of the controls in accordance with variations in atmospheric temperature. This can be seen from the following. The simple barometric device is unaffected by air temperatures and supplies a constant quantity of fuel for any given pressure. On a hot day, the air mass flow consumed by the engine at constant r.p.m. is less than at other times and consequently the air fuel ratio is richer and the combustion temperatures rise. Closing the throttle reduces the fuel supply but also reduces the r.p.m. set by the C.S.U. and hence the air mass flow. It follows that on a hot day, when the engine power is reduced anyway, a further reduction in power would be necessary, were the inter-connection not to be altered and maximum temperatures not exceeded.

The use of a barometric device having the correct compensation for temperature would obviate the need for this. In the best case, the compensation would be effected to maintain the combustion or the jet pipe temperature at the appropriate values, as this would also take account of any deterioration of the engine, although automatic compensation for atmospheric temperatures would be a great advance on relying on manual resetting of the controls. A compromise compensation for atmospheric temperature changes can be introduced by using a capsule in the barometric which is partially gas-filled, instead of being completely evacuated..

Using a barometric unit with compensation for jet pipe temperature variations, a comparatively slow response must be employed in the compensating device. The engine stability does not suffer from the conditions depicted in Fig. 6, because the controls in operation are the flow control and the C.S.U., and the flow control is reset over a period of time by the temperature unit.

Incidentally, it is worth commenting that on the simple constant pressure cycle, the optimum cycle efficiency is always obtained at the maximum speed, reduction in power being effected by reducing the combustion temperature. This is also the best for the life of the components; however, when due account is taken of the component efficiencies of the blower, turbine, and airscrew a variation in speed as well as temperature is found to be beneficial.

Optimum running conditions and the high blower and turbine efficiencies these require are only obtained at any particular engine speed, over a narrow range of operating points on the blower characteristic. It is the duty of the control system to keep the operating point within the permissible range at all times.

The individual shape of blower characteristic curves differ and each case requires separate consideration, but Figs. 6 and 7 indicate the general shape of the characteristics as applied to a blower of average design.

Figure 7 shows the blower characteristic curves with, superimposed, the results of controlling the engine in different ways. Each of the control lines represents the locus of the operating points under varying day temperatures. The optimum blower efficiency is normally obtained near the surge line, so that a control system which results in the operating line following almost parallel to the surge line will be preferable.

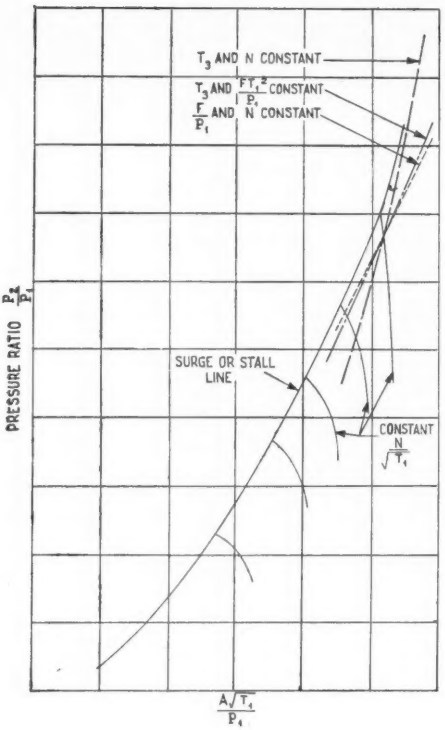

Fig. 7.
Compressor characteristic curves for a compressor turbine type engine.

Given values of r.p.m. and combustion temperature are the limits which must not be exceeded. A line is shown which depicts the result of keeping these constant. This has a tendency to approach the surge line at cold atmospheric temperatures, when the $N/\sqrt{T_1}$ rises (for constant N), and to fall away under hotter conditions.

The line showing F/P_1 and N retained constant is the line which can be obtained with a barometric device and a C.S.U. propeller, for example. It looks ideal, but this curve does not show up the fact that the combustion temperature gets excessive at high atmospheric temperatures. This setting of the barometric control would not be adopted in practice, for by the addition of a spring the characteristic can be faked to take account of the lower temperatures at altitude as calculated from the I.C.A.N. tables.

The third line shows a combination of temperature control (T_3) and a flow control set to maintain FT_1^2/P_1, constant. This T_3 is nearly parallel to the surge line, and of course avoids excessive values of temperature, but instead permits the r.p.m. to rise somewhat, which may be a somewhat less grievous fault.

There is another factor to consider besides the precise position of the operating point on the blower characteristic and its effect through blower efficiency on the engine's specific consumption; this is the variation in power resulting from these different control systems. Fig. 8 illustrates this. The power developed by the engine under I.C.A.N. conditions is taken as the datum figure and variations either way are expressed as percentages of this. The abscissa is taken as the temperature deviation from I.C.A.N. The curve is approximately correct for different altitudes. All three systems on Fig. 7 are shown here.

A factor which must be considered is that if the power output is allowed to increase

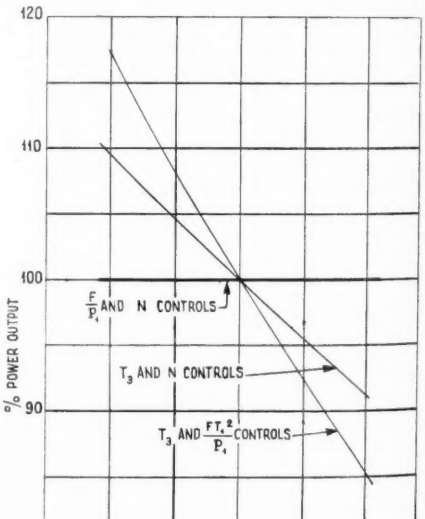

Fig. 8.
Effect of temperature variation on the power output of a compressor turbine type engine.

under cold temperatures to any extent, a penalty will have to be paid in the provision of a sturdier reduction gear than would otherwise be required, and this extra weight will still have to be carried by the engine under hot conditions when the power output is reduced.

7. DESCRIPTION OF UNITS.

The foregoing has given an account of the requirements of the fuel systems for the different types of engine, upon which variables the units should work, the rate of response and so forth. This section deals with the practical units and their installation on the engine.

7.1. INSTALLATION.

On the question of installation there are two diametrically opposed principles. Obviously, on the one hand, it is much easier to install a collection of smaller units connected by pipes on a closely cowled engine than one larger unit. On the other hand, pipe joints, particularly in the high pressure fuel systems used on turbine engines, are a potential source of leaks and so on, and it is desirable to reduce their number. This may be done by combining the fuel system components into, say, two main assemblies and connecting the individual components in the assemblies by interior ducting. This system cleans up the appearance of the engine very much, as well as having other cogent advantages, such as easy servicing and so on. But naturally the assemblies become bulky and the installation problems become difficult; in many cases they are specially adapted to fit the shape of the space available on the engine. It would seem that these difficulties will increase with time, as engines become more nearly buried in the wings of the aircraft and ever greater insistence is paid to reducing the frontal area of the engine.

An alternative would be to have an auxiliary gearbox in a compartment in the wing beside the main engine. The latter would be very much cleared up by this, all accessories being transferred to the auxiliary gearbox. When making an engine change, only one fuel pipe would need to be broken —the line to the burner manifold or to the distributor if one is fitted.

There are doubtless many objections to the scheme, but it may be preferable to introducing bulges in the nacelle lines. The present axial flow engine is so inherently streamlined that the fuel and accessory systems are bound to be something of a growth on it, and assigning them a place or compartment of their own would appear to be beneficial, both for the accessory design and for the main backbone of the engine.

7.2. GENERAL DESIGN.

General descriptions of all the units have been published in full elsewhere, so that it is only necessary here to mention their existence and the general principle of operation.[1, 2]

As to the general scheme of the controls, it is perhaps worth mentioning that the pilot's main engine lever controls the power of the engine from idling up to full power. To stop the engine, a separate high pressure shut-off cock is provided which cuts off the fuel entirely.

A question in the layout of the fuel system concerns the design of pump to be adopted. These pumps must be engine-driven for safety and overall weight considerations. All early engines used a fixed displacement pump of the piston or gear design. With these, control must be exercised by spilling off the surplus fuel, which the pump provides. Under altitude conditions this quantity may rise to nearly 90 per cent. of the total supply. The fuel which is recirculated in this way normally evolves gases and becomes very aerated with the sudden drop in pressure in passing through the spill valve, and it is usual to pipe it back to the fuel tank to avoid feeding the gases direct back to the pump entry; this involves some bulky and heavy pipework.

The alternative is to use a variable delivery pump and arrange for the control system to actuate this. The pump is then not merely a pump but an integral part of the control system. Fig. 9 shows such a pump. This is too well known to require description, except perhaps to say that an over-speed governor is incorporated. This works by employing the centrifugal pressure generated in some radial holes in the pump rotor, to operate a spring-loaded diaphragm which, in turn, opens a servo valve if the speed rises too high. Any control system employed with this pump need only open other such servo valves to obtain control of the pump delivery.

7.3. BAROMETRIC DEVICES.

These have been described too often to bear repetition. Briefly, there are four main

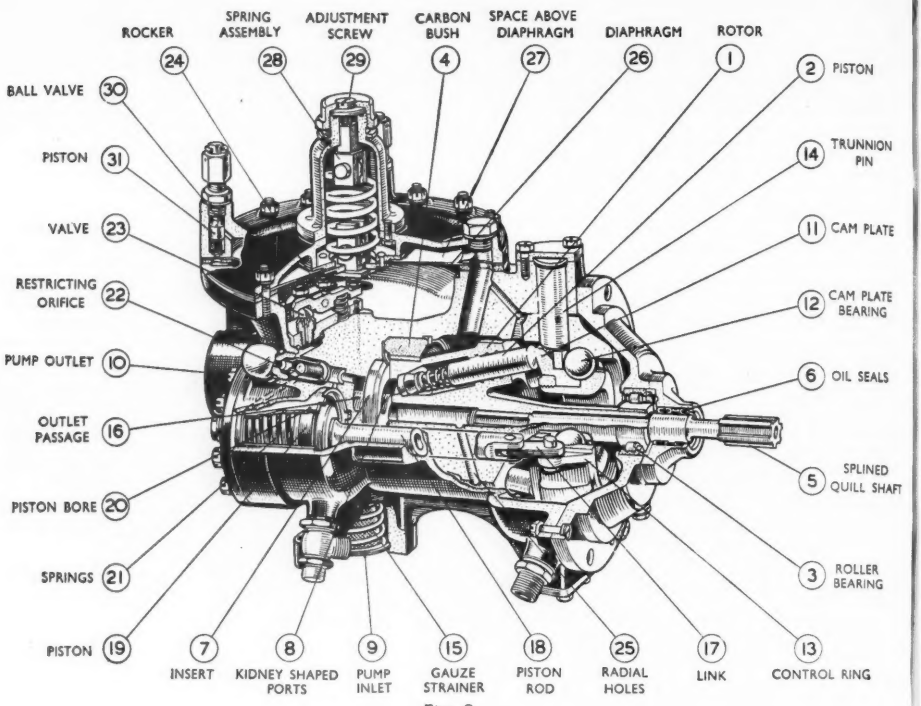

Fig. 9.
Arrangement of typical fuel pump.

variants, all of which depend for their action on the pressure flow characteristics of an orifice or orifices in series. For a given flow through the orifice a certain pressure drop results and by varying the size of the orifice the relationship is varied. The barometric devices work by balancing the pressure drop against a variable reference force, and also providing a variable orifice in the system. The basic differences in the units boil down to the selection of which function is performed by which variable. Fig. 10 shows the basic types diagrammatically. In each case, the units have been depicted as operating a servo valve, the opening of which will reduce the fuel supply through the unit by some means.

The first type is the original system as typified by the barostat or the barometric pressure control. The second is the simple flow control suitable for moderate altitude applications. The third is suitable for high altitude application but tends to be less stable under low r.p.m. conditions, while the fourth combines all the performance virtues of the others, but is naturally a more complex unit.

7.4. Temperature Control.

Several methods of attempting to control on temperatures have been tried, including differential thermal expansion, the rise of pressure in gas containers, the flow of the hot gases through systems of orifices and electrical means. The last named is now the favourite, and can almost be said to have arrived.

Two main methods exist. Both rely on thermo-couples in the gas stream for measuring the temperature. The e.m.f. from these is balanced on a bridge circuit against a reference voltage, control of the operating temperature being obtained by the pilot varying a rheostat in this circuit. The out-of-balance current is amplified and caused to actuate an electric motor to modify the fuel supply to the engine appropriately. Alternative means of utilising the electric signal are now under investigation.

Precautions must be taken against failure of the system, so that this cannot cut out an engine or interfere with its control beyond a certain degree. The thermo-couples must be

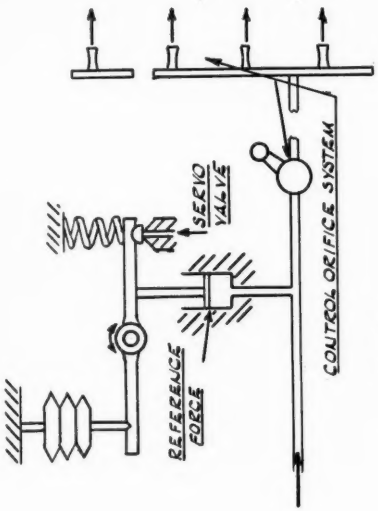

Fig. 10A.

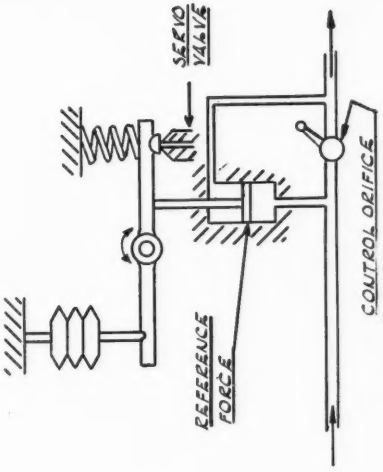

Fig. 10B.

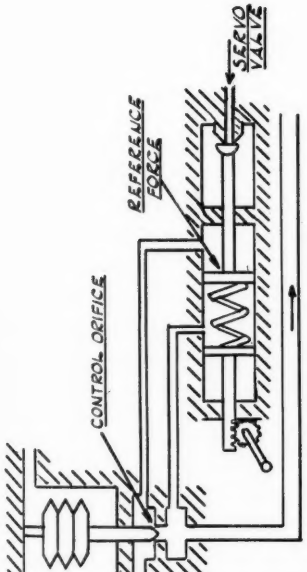

Fig. 10C.

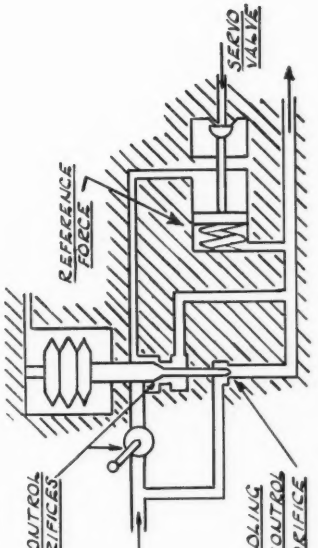

Fig. 10D. Barometric control devices.

very fragile if they are to have the necessary rapidity of response, and although they do not often fail, it is common sense to see that a failure will not be catastrophic. This means in effect that the control must be arranged so that whatever happens to the temperature control unit it must have the minimum of effect under idling and very low speed conditions, with proportionally greater effect as the speed is increased.

Promising results were reported from America in the early days on the use of a differential expansion system, using a quartz rod and metal sheath as the members: some success with similar experiments has been achieved in this country. While perhaps such methods will not compare with the results obtained from the electric systems, it may be that they will be good enough for certain applications and, being simpler, will be cheaper.

7.5. Governor systems.

The specification for a governor system is a difficult one to fulfil. Nevertheless, this has now been accomplished. It was nearly accomplished in the early days using the hydraulic governor on the fuel pump with a variable spring setting. Stability was obtained by fitting an anticipation device to slow down acceleration before the final speed, for which the governor was set, was reached. The acceleration control described below was employed to prevent over-fuelling. Stability over quite the whole speed range could not be secured, and the acceleration control was not sufficiently good at the low speeds.

Since that date, proposals for variable datum governing, that is governor control at the range from cruising to maximum speed, has been made with barometric control at lower speeds. This compromise is possible with a much simplified governor (compared to the all-speed unit) but has not been put into effect, partly because of the increased overall complexity of the system that it involves.

Another system for true all-speed governing, which has been engine-tested and has been found to give a very satisfactory performance under all conditions, has not been adopted, again because of the complexity entailed, relative to a simple barometric system. This system was to employ a variable delivery pump driven by the engine to pump servo oil through a flow control device. The flow control is arranged to control the supply of fuel to the engine in such a way as to maintain the flow of servo oil through it at a constant value. The engine speed is then regulated by adjusting the stroke of the variable delivery oil pump.

7.6. Acceleration control.

The immediate cause of accelerations in jet engines at any rate, is a rise in gas temperatures. It follows that a temperature control with immediate response would control accelerations; the avoidance of rich extinction on suddenly opening the throttle at altitude requires even more rapid response, not to say anticipation. But temperatures are a direct function of fuel air ratios and if these can be limited, the temperature will be. The required "anticipation" for avoidance of rich extinction is also provided, for the excess fuel is never even supplied.

A unit of this type has from time to time been put forward as a temperature controller or over-ride, but the need for compensation for atmospheric temperature effects (since they affect the combustion temperatures independently of the fuel air ratio effects) has prevented its adoption so far. Another disadvantage of the system from this point of view, is that the unit depends for its functioning on the area of the nozzle guide vanes. If these bow, the temperatures permitted by the control may increase.

The principle on which the unit depends is that the air mass flow through a choked nozzle varies directly as the air pressure and inversely as the square root of the temperature before the nozzle. In most engines, impulse turbines are employed and the flow through the nozzle guide vanes is choked for a very large part of the operating range—well below cruising speeds for instance. It follows that when the controlling temperature has been reached, the air mass flow will be directly proportional to the blower pressure. It is an easy matter to control the fuel so that it never exceeds a certain ratio of the blower pressure, and then the fuel air ratio will be controlled at the correct value. At speeds below that where sonic flow in the nozzle guide vanes exists, the control permits increasingly richer fuel air ratios.

8. STARTING CONDITIONS.

The process of starting an engine depends on a combination of three separate effects. First, the fuel and the air must be provided in the right ratio for ignition, the fuel being in an appropriately atomised state; second,

ignition must be applied to the spray to start the fire; and third, the engine must accelerate up to idling speed from the speed at which ignition takes place. This last is ensured by providing starter assistance up to an adequate speed.

The timing of the separate events is of importance in obtaining the best starting with the minimum of drain on the battery.

8.1. Control of the starting air and fuel.

The air supply is regulated by controlling the speed of the engine by means of the starter.

The burners must be provided with a certain minimum flow of fuel before an atomised spray can be obtained. Also, all the manifolds and fuel pipes must be filled.

If, as in early engines, the capacity of the fuel pump fitted were only just sufficient to cater for maximum speed requirements, then there would be a long delay before an ignitable spray was obtained and the speed at which this occurred would be relatively high, unless additional starting fuel was supplied by some outside means.

Also, fuel dribbled through the bottom burner into the combustion chamber unless this was prevented, while the engine was running up to the ignition speed and the manifold was filling. Ball valves were sometimes fitted in the burners to prevent the dribbling trouble, but in our experience were not very satisfactory.

Since the time to fill the manifold is of consequence the starters will be dependent on the degree of fullness of the manifold. This will vary between the case of an engine which has been left for a day and one which is restarted immediately, unless some special measures are taken, such as positively draining to atmosphere or "dumping" the fuel in the manifold on each occasion.

(a) Starting pump system.

One method, adopted on early engines and used to this day on one British engine and on American engines, was to fit a separate electrically-driven starting pump. A relief valve limited the maximum fuel pressure obtained from this pump and therefore, the maximum fuel flow to the engine until the speed was high enough for the main fuel pump to deliver the flow, when the starting pump was cut out.

(b) Accumulator system.

On the early engines, starting was accompanied by a burst of flame passing right through the jet pipe and out of the tail. This was thought to be damaging to the turbine blades. The accumulator system was designed to eliminate these flames.

In its essentials, the accumulator system comprises a "dump" valve, and a hydraulic accumulator. The "dump" valve remained closed until the fuel pressure rose to a given value, during which time the accumulator was charged from the delivery of the main fuel pump. The capacity of the accumulator was sufficient to fill the manifold with a little over: this surplus was added to the flow from the fuel pump and resulted in a burst of fine spray which was readily ignitable. The correct degree of excess was found on the engine by trial and error, too little causing difficulty in accelerating away from the start and too much an excessive amount of flame.

The dump valve was also employed to drain or "dump" the fuel in the manifold on shut down of the engine. By employing a double diameter construction, it was possible to make the valve open at a relative high pressure but close at a very low one. On shutting down the engine, the valve eventually sprung shut, and in so doing, uncovered a drain to atmosphere and dumped the fuel in the manifold. So as to carry out this dumping action, it is necessary to fit the unit at the lowest point of the manifold.

Figure 11 shows a modern example of this system as fitted on the Derwent V. Dumping is effected by the operation of the shut-off cock in this case, instead of by the automatic valve. The cock, in the shut position, uncovers an atmospheric drain to the burner manifold, as well as connecting the fuel delivery line back to pump suction. (A feature adopted to balance the cock.) The discharge of the accumulator is regulated by a diaphragm type "trigger" valve.

It should be remarked that the accumulator does have an effect on the acceleration of the engine under certain conditions, although it is a minor one. It is clear that under idling conditions at altitude, the burner pressure may drop below the accumulator discharge pressure. Consequently, the accumulator discharges during the deceleration, prolonging by a second or two the time this deceleration takes and, conversely, on acceleration it charges, taking fuel which otherwise would be helping to accelerate the engine. This puts

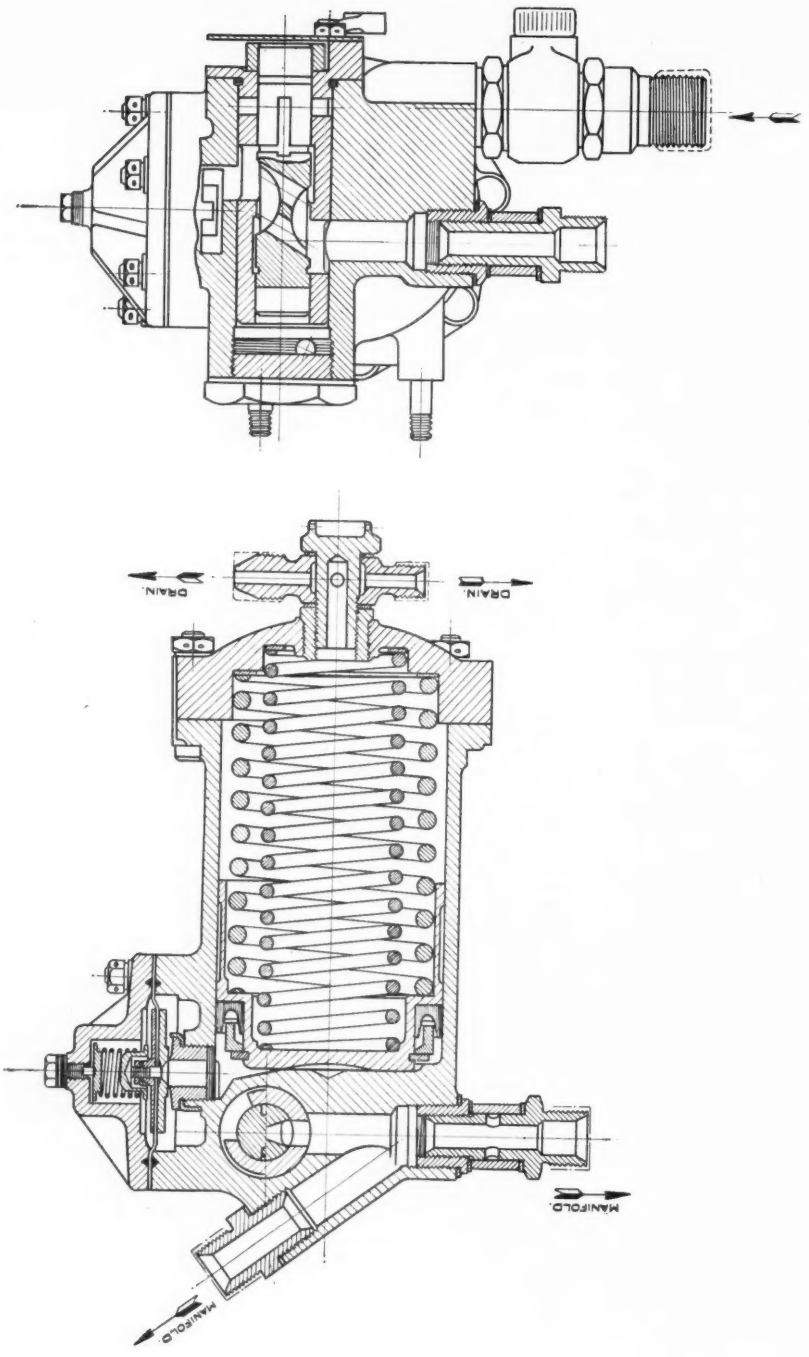

Fig. 11.
Arrangement of combined accumulator, trip valve and high pressure cock.

a slight kink into the shape of the acceleration curve, but is not otherwise serious. The difference in accelerating times has been shown to amount to 0.7 secs. at ground level.

To digress for a moment. Reference was made to bursts of flame through the turbine occurring on starting on early engines. It was not until long after that it was appreciated how seriously this flame beyond the turbine actively hindered the acceleration of the engine by setting up a back pressure in the jet pipe. In particular cases, flame vibration and resonance occurred where the jet pipe length favoured this; starting could then be effected only by accelerating the engine through the resonating speed band by brute force and a powerful starter. Methods of detuning the jet pipe and altering the resonating frequency and of damping the pulsations are known, but the phenomenon can still make starting awkward.

(*c*) *Flow boosters.*

The accumulator system is not suitable, where quick starts are required, because the accumulator must be charged from the fuel pump delivery before it can be discharged. This means that there is an inherent delay before the fuel issues from the jet and ignition can take place.

This led to the development of the "flow booster," which can be likened to being a single-stroke piston-type starter pump. Two forms of this unit have been made—one for moderate starting times of 5 or 6 seconds and one for "immediate" starting.

In the case of the 5-6 second starting unit, the manifold is partially filled by the fuel pump. At a predetermined setting, a valve, sensitive to flow, closes, shutting off the pump delivery from direct connection with the burner manifold, and diverting it to the flow booster itself, a double diameter piston device. The flow is directed on the smaller piston diameter and results in an amplified quantity of fuel being displaced by the large diameter. When the flow booster reaches the end of its travel, a spring-loaded bypass valve opens to direct the fuel flow to the manifold. The flow booster itself is recharged on shut-down.

Such a flow booster is a smaller and lighter unit than the equivalent accumulator; it allows for quicker starts to be made and will not interfere with the acceleration even to the minor extent that the accumulator did, since it remains discharged, once the engine has started, until the shut-off cock is closed again. Nevertheless, it is a somewhat more complex and tricky unit than the accumulator. Now, with further advances in the technique of starting, this unit is no longer required.

For immediate starting, the design of the flow booster is much simplified. The unit must have a capacity equal to the manifold capacity plus the requisite surplus to give the ignitable spray. Immediate starting is done by means of a gas cartridge starter; the source of power for the flow booster is made to be these gases. The unit itself again consists of a double diameter piston with the cartridge gases now operating on a very small diameter. A collection of spring-loaded ball valves ensures first, that the discharge from the flow booster does not feed back up the main pump line, but does go to the manifold; second, that excessive pressures are not built up in the unit by leakage back from the fuel system when this is operating at high pressures; third, that the flow booster is not recharged from the fuel supply to the engine; and fourth, that the accumulator is recharged from the tank booster pumps.

(*d*) *Two-stage starting.*

On certain of the newer and smaller engines the accumulator system is not used. A simpler system, the two-stage starting system, is adopted.

In this, it is arranged that initially all the fuel supplied to the engine shall be supplied through a proportion of the total number of burners only. Due to the relatively large quantity passing through each operative burner, good atomisation is obtained. The system resolves itself into requiring as extra equipment only the provision of some extra pipes and a small electrically operated spring-loaded control valve. The few cans ignite and burn and the speed of the engine increases. As the fuel pressure increases, the control valve lifts off its seat to allow some fuel to reach the other burners. At the end of the starting cycle the current is cut and the valve opens fully. A dumping action is still required, which can be effected positively, as on the Derwent V, as a result of operating the shut-off cock.

This system was also considered as a possible means of obtaining better atomisation at altitude under ordinary running conditions. There were several objections. With all the fuel being concentrated in a few cans, the fuel air ratios would be very high and the engines liable to rich extinction, to

say nothing of high temperatures. The temperature effect would be the worse since the non-uniformity of temperature distribution would introduce thermal stresses.

(*e*) *Larger engines.*

The starting of larger engines is now accomplished without accumulators. This is made possible by the use of burners giving a finer atomisation under starting conditions (Duplex and so on), by the adoption of the torch igniter (described below) and by the far greater fuel pump capacities now provided on some engines. The last-named occurs on engines with duplicated pumps.

As a result of the better burners and the higher fuel flows, an ignitable spray is produced quite quickly and the torch igniter lights this immediately.

8.2. IGNITION SYSTEM.

The ignition system adopted on most engines to date has been to employ a trembler type booster coil of standard design and use this with sparking plugs basically of standard design; the plug electrodes are far from standard and vary from engine to engine however, and also from time to time. This is because of the rather arduous duties they have to withstand. To get a consistent start the plug points must be immersed in the spray issuing from the burner, but they must not get too hot and be damaged when the engine is operating at maximum power. Finding the right location for the plug and a suitable design of electrode is a matter of considerable complexity requiring much experiment.

The shape of the electrodes varied from engine to engine for the following reasons. Spark ignition is the ideal form and is possible under favourable conditions. If the plug points are allowed to get hot, much more reliable and certain ignition is possible. A compromise must be struck between slender electrodes which will heat up more readily, and sturdy electrodes for mechanical reliability. Many laboratory tests have shown the great benefit that may result from even warming the electrodes.

Full-scale ignition and starting tests on engines are complicated by the critical nature of the air flow about the plug. Ventilating holes on the plug body direct cold air on to the electrodes to cool them under operating conditions. The precise siting and location of these ventilating holes is of importance, as is the presence of any other jets of air. These may come, for instance, through the clearance between the hole in the flame tube and the igniter plug body. Manufacturing tolerances and idiosyncracies of the air flow pattern may influence these currents of air; in turn, these will affect the shape of the fuel spray and ignition conditions to a great extent. The cone angle of the burners also had an important bearing. Lubbock and Duplex burners have the pleasant characteristic of large cone angle under starting and low flow conditions, so that the electrodes can be immersed in the spray on ignition, the cone angle shutting down to a smaller one at the higher flows. On Simplex burners this does not occur.

Gradually it became clear that the simple expedient of fitting an igniter plug in the flame tube was not sufficient to cater for the more arduous duties of ignition, such as under flight conditions at over 20,000 feet. The torch igniter was designed in the first place by K.L.G. to get over these problems. This unit was an ordinary igniter plug, with a subsidiary supply of fuel to it. The fuel was injected through a small hole on to the plug points. As a result a torch of flame would be projected across the flame tube from a secluded point on the combustion chamber which was cold, so that there was no danger of the plug points suffering from the high "maximum power" temperatures. This design was later improved by The Lucas Company by incorporating swirl atomisers for the atomisation of the subsidiary fuel supply for the torch. A still further improvement was effected by paying attention to the air flow around the burner and directing it in the right manner.

The torch igniter requires a fuel supply which is provided by a dual purpose unit known as the minimum pressure and torch igniter reducing valve. This takes fuel from the main fuel pump line and, by employing a reducing valve, maintains a reservoir at a constant fuel pressure of perhaps 35 lb./sq. in. This fuel pressure is set up immediately on starting and is available for feeding to the torch igniters. It is also made use of in controlling the idling speed of the engine. As we saw earlier, the engine's idling speed must be made to rise at altitude, as otherwise, due to the reduced combustion efficiencies at very low pressures, there will be difficulty in controlling the engine to run stably. One convenient method of adjusting the idling

speed is to maintain the burner pressure constant, and that is what this unit does. A small relief valve is set to open and supply fuel from the constant pressure reservoir to the burner manifold, if the burner pressure falls below a certain fixed value of about 10 lb./sq. in.

8.3. Electric starting and control panel.

The electric starters themselves are of comparatively orthodox design; some have been series wound, in which case an over-speed cut-out device is required, and others compound, when this extra could be foregone. In many cases, where a control panel is fitted, cushioning of the starter engagement is done electrically instead of by the conventional clutch system.

The control panel is the "brains" of the starting system. It controls the sequence and timing of all the events. Fig. 12 shows such a unit.

To initiate a start, the shut-off cocks must be opened, the engine throttles closed, and the tank boost pumps operating. An inter-lock switch prevents the panel operating until this is done. Next, pressing the control panel switch winds up a clockwork time mechanism. A cam-controlled switch ensures that once this starts operating, further pressing of the switch will have no effect until the cycle is completed. The cycle period is about 30 secs. As soon as the panel switch is released, the time cycle starts; its first action (acting through relays) being to complete the circuit to the booster coils and to the torch igniter solenoid valves (if torch igniters are fitted), and also the main starter motor circuit, but with a large starting resistance in series. The starter motor starts to revolve slowly and take up the backlash in the engaging mechanism. Some five seconds later, a second magnetic relay short circuits the starting resistance. In some cases, the starting resistance is made in two units, when the first resistance is cut

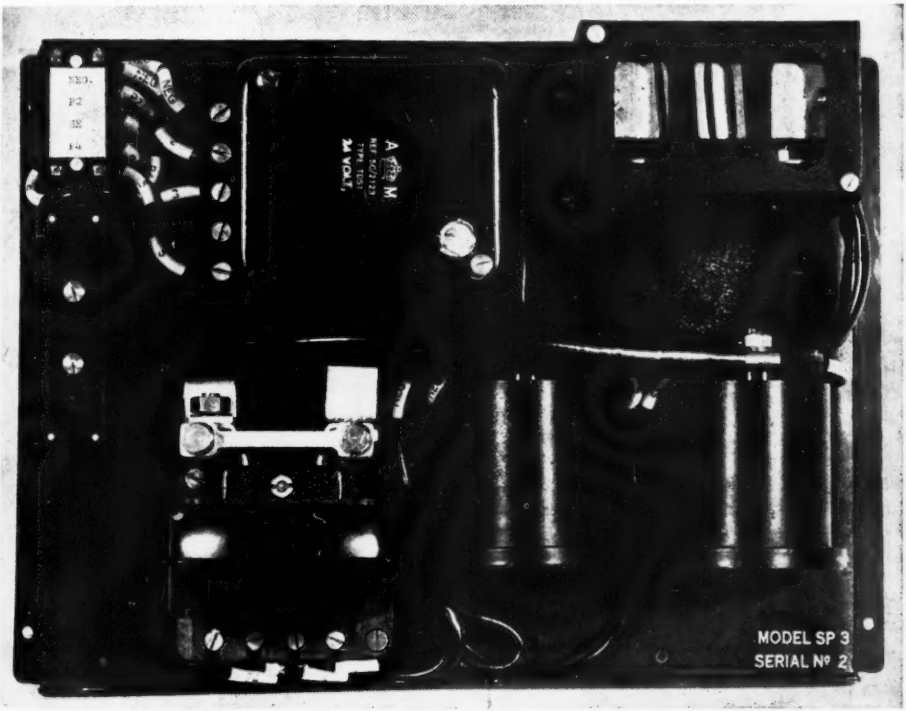

Fig. 12.
Single unit starting panel.

out after five seconds as before, and the second remains in for a further period, being short circuited when the engine has gained some speed; this reduces the peak current values. If two resistances are employed, choice of these gives control of the speed of acceleration. The final resistance must be cut out soon after ignition takes place, *i.e.* the accumulator has discharged, but not before, for fear that the higher engine speed and air flows will impede satisfactory ignition.

More recently, the control panel is being discarded, mechanical clutches providing the soft engagement, a thermal trip and a speed sensitive trip guarding the starter against excessive speeds or temperatures.

8.4. Cartridge starters.

Electric starting was universal at first, but as engine sizes started to increase, the weight of the necessary electrical equipment went up by leaps and bounds. An alternative system, that of cartridge starting, is now in an early stage of development. It is particularly applicable to military aircraft, but on civil airlines, the noise might disturb the passengers' peace of mind. The cost of the cartridges and the special care needed in the storage of explosives also militate against the new system.

On a military aircraft these considerations no longer apply; further, it is a requirement that the aircraft must be independent of starter trucks or other ground starting facilities, and six consecutive starts under cold conditions must be possible.

The reasons for the heavy weight of electrical equipment can be stated as follows. The turbine engine, unlike the piston engine, has to be run up to a fairly high speed, say 1/10 maximum r.p.m. or higher before it will maintain itself. Usually ignition takes place at perhaps 1/20 maximum speed and starter assistance is required to the higher value. Now the electric starter can be of the same sort of size as on piston engines, but the prolonged drain of current on the batteries, particularly under conditions of extreme cold, necessitate a great increase in battery capacity. Modern engines tend to increase the problem in so far that axial blowers are coming to the fore and these normally appear to have a higher moment of inertia than an equivalent centrifugal blower. The addition of a propeller and reduction gearing with the attendant oil drag under cold conditions also increases the power required for starting.

Slow-burning cartridges appeared to be the easiest method of providing the necessary power. The use of hydrogen peroxide, as employed by the Germans in the Walter rocket engines, has also been considered, but this is nasty stuff, usable in time of war, but a little dangerous for peacetime. Moreover, it has few advantages over safer propellants.

It can easily be seen that the greatest economy in cartridge powder will be effected by accelerating the engine up to speed as quickly as possible. The majority of the starter power will then be absorbed in overcoming the inertia of the engine and the minimum by friction. As the starting times reduce to very short periods, this effect becomes of less and less consequence.

The use of very short times implies the use of very high torques, and this supplies the bottom limit for starting times.

To return for a minute to the choice of propellant. The whole *raison d'être* of the cartridge starter is to provide a large amount of power; consequently the higher the energy content of the propellant, the smaller the amount that is required. This means using high pressures and temperatures, but providing for these means a heavier construction of starter, and a compromise must be struck. There is an important point concerning temperatures, however. It takes time for heat to enter the starter and therefore, it may be found that a higher temperature propellant, the use of which results in shorter starting times, heats the starter up to a less extent than with a relatively lower temperature charge.

The power of the cartridge gases can be extracted in a piston unit, as in the Coffman starter, by a vane type motor or by means of a turbine. The last-named type offers the most promise and we have some experience of it.

The design of these starter turbines is rather different from other turbines, for they do not run at a constant speed. Impulse turbines work most efficiently when the wheel tip speed is equal to about one half the jet velocity. But here the jet velocity of the high pressure gases from cordite will reach issuing velocities of some 7,000 ft./sec. (a Mach number of 2.3) in expanding to atmospheric pressure. To run a turbine at a tip speed of 3,500 ft./sec. is obviously impossible, so there is a choice to be made between using a two-

stage turbine or running the turbine "inefficiently." The provision of a two-stage turbine implies extra weight in construction and greater difficulties in the general design, which must be offset against the saving in cartridge charge.

It is clear that maximum efficiency, *i.e.* minimum cartridge charge, will result from running the turbine wheel at as high a speed as possible. But the choice of propellant used must not be dictated by considerations of turbine efficiency. A propellant with low energy content per pound will produce lower gas velocities, therefore higher turbine efficiencies are possible, but the power of the turbine starter obtained from a given weight of propellant is materially reduced.

At one time, directing the cartridge gases on to the main turbine wheel was considered. The relatively much lower tip speeds of the main turbine wheel, compared to those of a starter turbine, required the use of much more cartridge; apart from this, the cartridge gases were liable to damage the main turbine blades.

Fig. 13.

An experimental starter was designed to explore the different problems by practical test. Naturally, in the circumstances, it was conservatively designed, but much useful information has been obtained on these tests. Fig. 13 shows the starter itself and Fig. 14

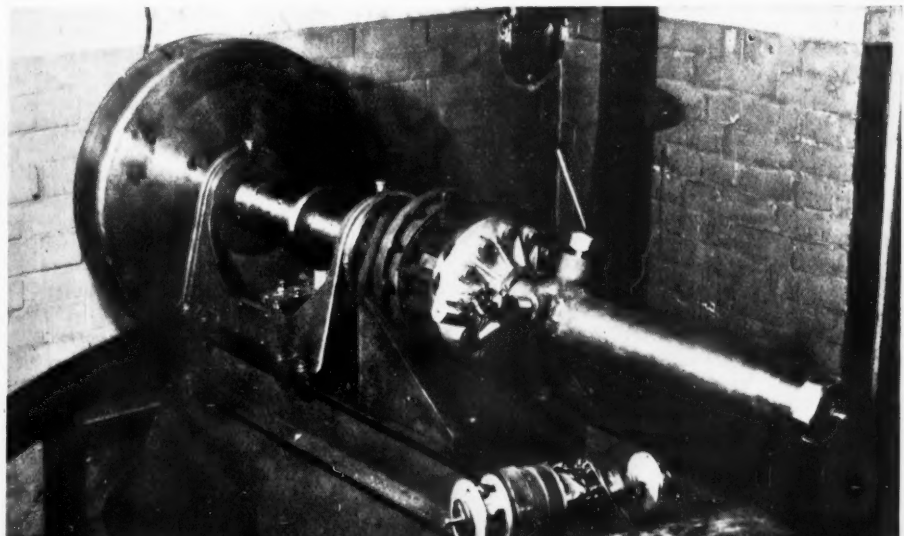

Fig. 14.

shows it mounted on its test stand, coupled to a flywheel of 300 lb. ft.^{2} moment of inertia. This unit has developed a peak h.p. of 425 h.p. on test.

From the tests, we have discovered that the torque remains approximately constant, independent of speed, and that a starting time of about two seconds should be used. The present unit could speed an engine of moment of inertia of 300 lb. ft.^{2} up to just over 1,000 r.p.m. with a cartridge charge of $1\frac{1}{2}$ lb. of cordite. Keeping still within the range over which experimental evidence has been obtained, although with slight changes to the unit, we can anticipate obtaining the same results from between $\frac{3}{4}$ lb and 1 lb. of charge.

ACKNOWLEDGMENTS.

In conclusion I should like to acknowledge my thanks to the Directors of Joseph Lucas Ltd. for permission to publish this paper, and especially to Dr. Watson, who has continually guided and encouraged me since I first started work on these engines. My thanks are also due to my colleagues and friends in the Industry with whom I have discussed these problems.

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DISCUSSION

Dr. Watson (Chief Engineer of the Lucas Group): In the early days there had been a feeling that the control of jet engines—and only jet engines were talked about then—was very simple. They turned on a tap, and if they wanted to increase the speed the tap was turned on a little more. But, as Mr. Lawrence had shown, the problem was not quite so simple as that, and it seemed that the control of the jet engine, and still more the propeller-turbine engine, was just as difficult a problem as that of controlling the piston engine.

In principle, there were two lines of attack. One, to endeavour to anticipate how much fuel the engine would require for a given altitude and speed and arrange to meter out to it the anticipated amount; the other was to employ a parameter, such as speed, and devise a system which would adjust the fuel until that speed was attained.

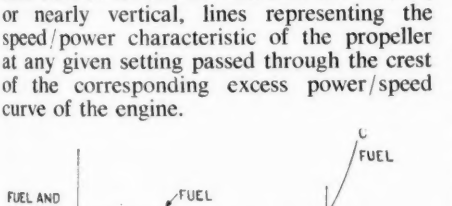
Right from the start of jet engine development the existence of these alternative control means was realised and there had always been a conflict of opinion between the advocates of the throttle valve control on the one hand and the speed governor or its equivalent, on the other. In those days the intensive work on servo mechanisms had not been published. If it had, the systems would have been referred to as open and closed loops respectively. Also no publication had been made of the conditions of stability in closed loop systems, although it was known that engine governors under certain conditions could hunt. The engine governors on the early jet engines certainly did hunt, particularly when fine governing was aimed at, so much so that in the latter portion of the war the standard salutation among members of the author's organisation was, in the words of General Montgomery "Good hunting."

For this reason up to the present the control systems in this country had so far all been designed on the open loop system where they tried to anticipate what fuel the engine wanted and to give it that. After all, the only factor that would control the engine was the amount of fuel supplied to it. Mr. Lawrence had pointed out the disadvantages of that type of control and the difficulty in making accurate anticipation of what the engine would require under operating conditions. Not only were there so many variations in conditions such as temperature, pressure and aircraft speed, but an engine might suffer damage or deterioration which would alter its operating characteristics. Hence, no matter how hard they tried to anticipate what fuel the engine would require they would sometimes fail to achieve the desired result and the engine might run too fast or it might over-heat. The system, therefore, that would control the engine on the closed loop principle in terms of, say, speed or temperature had many advantages and Mr. Lawrence had given the pros and cons of a number of them.

In America a certain amount of progress had been made with controls on the closed loop system and work which was being

done in this country at the present time would probably eventuate in controls of this nature.

Mr. Lawrence had stated that on a simple constant pressure cycle optimum cycle efficiency would always be obtained at maximum speed. It would seem that a simple way of looking at the facts in the actual case would be to take the fuel consumption curve of the system in the unloading condition, *i.e.* with the propeller in neutral pitch and then consider what would happen if the fuel were kept constant at any value while the speed was changed by altering the loading. Thus on the figure curve ABC would represent the no load fuel line. For a fuel quantity represented by the horizontal line BD regions to the left of B would correspond to excess fuel and available excess power. As one moved to the left the efficiency would decrease and engine temperature rise and, at zero speed no power would be available. The excess power available would, therefore, have an optimum value at some intermediate point along BD corresponding also to optimum efficiency. As point B was moved progressively downwards the speed at which this optimum efficiency occurred would clearly fall and the linkage between the setting of the C.S.U. and the setting of the fuel control should be such that the vertical, or nearly vertical, lines representing the speed/power characteristic of the propeller at any given setting passed through the crest of the corresponding excess power/speed curve of the engine.



Perhaps it was not generally realised that the problem of ignition in the case of a turbine, or any engine using a relatively heavy fuel which had to be atomised by spraying, was different in many respects from the problem of ignition in a petrol engine where the fuel was already vaporised.

In a petrol engine where the fuel was vaporised prior to admission to the cylinder, a spark of extremely small thermal energy was sufficient to ignite it, but in the case of the gas turbine where atomised fuel of low boiling point and high flash point had to be lighted, the first duty of the ignition system was to vaporise the fuel and if it were once vaporised it was fairly sure to light. This meant that the booster coil had to provide quite a lot of heat energy and not just a single electric spark.

The Americans had developed recently what they called a high frequency ignition system. The system was an elaborate one employing a high tension D.C. rotary transformer charging a capacitor which was intermittently discharged to give a series of high frequency impulses, with an energy content appreciably greater than could be given by the ordinary booster coil. This certainly did liberate a large amount of heat energy in a relatively short space of time, but it would seem to be a complicated method of producing heat and he wondered if, in view of the fact that the main duty of the plug was to vaporise the charge, a hot wire igniter might not be simpler and equally satisfactory.

Starting had progressed a long way since the original days of the Whittle engine, but it would appear that the horse power of the starter motors had increased in a far greater ratio than the horse power of the engines which they started.

For tests on the original Whittle turbine an Austin Seven motor-car engine was fitted for starting purposes. It was not a very big jet engine, but Air Commodore Whittle wished to be on the safe side and had provided a 7 h.p. engine to make sure of starting it. The starting tests had shown that nothing like so much power was required and ultimately the jet engine was actually started with the electric starter off the Austin Seven —a starter which gave at the most some 3/4 h.p. It seemed to him that there was rather a big ratio between the power developed by the small starter and the 300-400 h.p. mentioned in the case of the recent cartridge-operated gas turbine starters and he did not think the thrust or power of the main engine had gone up in quite that proportion. He admitted that in modern engines with high compression ratios the moment of inertia was considerably increased and in the case of axial compressors there might be difficulties with stalling during the starting operation.

In the original tests a starting period of some 15-30 seconds was acceptable but the

requirements now were that the engine should be started in the shortest possible time, in some cases two to three seconds, and this demanded a very great increase in the starting power. There were probably further advantages also in fitting a starter of ample capacity in that it reduced the risk of damage which might result from a slow start, which was almost invariably a hot one and might lead to damage to the engine in the hands of an inexpert pilot. Nevertheless these high starting horse powers meant that it was quite impossible to start the engine off the aircraft battery and some other means must be provided.

He was impressed by the scale of, and the amount of, ground covered by the paper. Mr. Lawrence had done an extremely valuable piece of work with the Lucas Company. The paper had been an eye-opener to him personally, and he congratulated Mr. Lawrence very much indeed.

I. Lubbock (Shell Petroleum Co. Ltd.): As Dr. Watson had said, at first sight it would appear to be a simple matter to control the flow of oil through a burner; that was done frequently. But those who had struggled with oil-burning devices had soon realised that even in simple industrial applications there were quite a number of difficulties about doing that accurately and with unfailing regularity, so much so that there was a standard problem in oil burning, known as flame fading.

Those devices which were controlled by ordinary valves did not remain controlled. That difficulty created trouble in the industrial application, to the extent that people were forced to move over to metering pumps, because oil changed its viscosity and the orifices, when controlled by needle valves and such like, seemed to vary the amounts they passed from time to time, and it was necessary to look around for other means of controlling oil flow exactly. Mr. Lawrence had shown how vastly more complicated that simple aspect of it became when it was bound up with the operation of an aircraft. Those who had burned oil through pressure jet burners on a boiler, for instance, knew that for a given set of atomisers which might be in the furnace at the moment, the pressure could be varied and that variation of pressure was usually effected by means of a pump, which could increase or reduce the pressure when necessary. There was a pressure-regulating valve, and the burners were operated to a certain pressure; when they wished to reduce the load simultaneously on all the burners they moved the pressure-regulating valve down. But the pilot of an aircraft could not be expected to screw pressure-regulating valves up and down, even though his aircraft might be operating at one height in the air. The paper had given an interesting account of means of meeting that problem and of how ingeniously it had been tackled by designers.

It was a curious fact that most of the gas turbines in service had used steadily, throughout the years during which they had been developed, the simple atomiser. Mr. Lawrence had mentioned the other types which could be used, such as the variable slot type. Could Mr. Lawrence explain why the simple atomiser had held the field for so long, and why there had been so much reluctance to move into the regions of more complicated burners which did not require such a big pressure range for their operation?

In a certain arrangement which his own organisation was developing for an industrial turbine application, they had adopted a variable slot cum spill type of burner, which gave a range of over 30/1 at practically constant oil pressure. That might reduce one of the problems, but would not solve it entirely.

The author had rendered particularly good service by pointing out one of the difficulties about the spill burner which was not always appreciated. With spill burners operating on pressurised combustion chambers the stage was readily reached at which, instead of spilling oil, they would be attempting to spill high pressure combustion gases back down the fuel line.

Dr. Watson had not given quite the full details of the ignition trouble. If a spray of oil were formed with various air-regulating devices around it, and if they wished to ignite the spray by means of an electric spark discharge, they had to place the electrode — assuming they were using a normal high tension spark—in exactly the right position relative to the shoulder of the spray. They relied on the air carrying the ionised gas discharge into the spray, and positioning was quite critical. The difficulties that would arise could be imagined, therefore, if the angle of the spray varied. Dr.

Watson went to the artifice of using much smaller chambers and equivalent smaller spray and ignition electrode, for they were more foolproof as regards ignition, and he lit the auxiliary torch which, of course, lit the main burner.

He would not recommend hot wire ignition because the problem it involved was similar to that which had been experienced with ordinary industrial oil burners for many years and which had caused an enormous amount of difficulty. When it was tried it was found that the hot wire blew cold almost immediately; so that there was a tendency to go to very much heavier wires and ultimately to using carborundum tubes and then they just about managed to effect ignition. He believed the trend towards high amperage brush discharge, and things of that kind, might help.

The Americans, on some of their industrial turbines, appeared to be so anxious about the starting problem that they had standardised on acetylene for igniting.

He was interested in the gas turbine starters because the problem was brought to him at one time and he had collaborated with Rotax Ltd. in the early days, using different kinds of propellants. Cordite had been mentioned by the author, from whose remarks he had assumed that he was using cordite in the well-known method of all-surface ignition. No doubt the author would be fully aware of the "cigarette-end" burning types, and so on, and the low temperature cordite.

R. G. Worcester (*The Aeroplane*): Could the author explain the phenomenon which, he believed, was known as "wet starts," which seemed rarely to occur at the manufacturers' works, but was often seen in service!

The author had said that when an engine was started a large flash playing around the tail pipe was noticed. Did that cause as much damage as one would imagine?

E. L. Bass (Shell Petroleum Co. Ltd., *Fellow*): All British fuel systems had been developed almost exclusively for the kerosene type of fuel. At the moment it was not entirely a certainty that all turbine engines in future would be able to operate on such fuels, and the tendency might well be, purely on the score of the availability, that they would have to operate on a more volatile type of fuel. There seemed little doubt that if that came to pass there would be a great deal more work to do because, apart from anything else, the higher vapour pressure of the more volatile fuels would introduce new problems. For example, in the aircraft installation there would be such things as booster pumps and tank pressurisation to be considered, and in the design of the engine system itself some arrangements might have to be made to cope with the volume of gas developed at altitude.

From the combustion chamber angle it rather looked as though more volatile fuels would offer certain advantages. Experiments in his organisation had shown that starting would certainly be improved, that such factors as flame stability would be better and that carbon deposition would be diminished. Unfortunately those advantages would be gained at the cost of some undetermined reduction of the safety factor. In the turbine engine they had a potential power unit capable of burning very much safer fuels than had been used in the past, and it would be a pity to have to abandon that advantage purely on the score of the lack of suitable fuels.

There were two points of considerable importance on the question of filtration. First, it had been found with the kerosene type of fuel that, almost independent of its physical freezing point as determined in the laboratory, separation of the water dissolved in the fuel occurred at temperatures round about $-20°C$. This tendency was, to some extent, dependent on the aromatic content of the fuel. He did not know yet whether or not trouble had actually been experienced because of the separation of ice; perhaps aircraft had not yet been flown for sufficiently long periods at altitude for the fuel to be cooled down sufficiently to cause the trouble. But they could envisage long range aeroplanes flying at great heights, where the fuel would be reduced to the ambient temperature which introduced the possibility of trouble in some parts of the engine because of the collection of ice.

Second, the standard demanded in respect of the cleaning and filtration of the fuel for delivery to turbine-engined aircraft was very high indeed on account of the delicate digestive organs of the engine fuel system. He had heard of a requirement for filtration to 5 microns, and it was extremely difficult to ensure that the fuel was cleaned up to that

extent, especially when the great thirst of the turbine-engined aircraft was borne in mind and the increasing demands for high rates of fuelling them. From that point of view it was interesting to note the author's reference to the air injection type of nozzle. He wondered whether or not the development of that type of nozzle would, in fact, alleviate the filtration problem as they saw it at the present time.

He felt it desirable either to provide the required filters in the aircraft engine installation (assuming a more reasonable degree of filtration by the ground equipment) or better still to make the engines less sensitive about the size of solid particle they could digest.

His organisation had done a certain amount of work on starting at low temperature conditions, and there was no doubt that the higher volatility fuels, *i.e.* going from the kerosene to the gasolene type, did provide improved starting. But the shape and nature of the spray, and location of the spark plug were really the over-riding factors. The torch igniter offered obvious advantages and he felt that if that type of igniter were coming into general use they might have to study the best fuel characteristics for the igniter itself. Possibly, in order to attain the desired starting characteristics, a bi-fuel system would be necessary in the end, especially for the starting of engines in the air after long periods of shut down, when they had been thoroughly soaked at low temperatures.

S. H. Evans (*Fellow*): The lecturer had said that gas turbines had to be operated near their top limits for satisfactory performance. From the viewpoint of the aircraft designer, he believed this well-known characteristic was likely to have a profound influence on the aerodynamic conception of the airframe, since in the case of, say, a line-abreast four-engined layout, it might conceivably necessitate the cutting out of one engine for economical cruising performance, thereby producing difficult control handling problems. He suggested that current orthodoxy in this respect was quite unsuitable for the multi-jet aircraft of the future, since the airframe designer was surely passing up one of the best features of the turbo-jet engine: namely, the absence of propellers and the latent possibility of packing all the power plant close together near the centre-line of the aircraft. He recalled one jet bomber now in the prototype testing stage in America, wherein not merely four, but six engines were spread externally across the wing span, presumably for structural reasons. Aerodynamically, the result struck him as a blind alley — a retrograde step hardly worth exploiting.

He felt that they were now passing through what might be called an overall design "transition régime," in which the airframe designer should be encouraged to reorientate his whole viewpoint. They needed, to visualise the exciting possibilities of the turbo-jet engine in relation to the aircraft configuration—to return to the drawing board to start from scratch all over again. They ought never to lose sight of the major concept that an aeroplane owed its sustentation, aerodynamically and economically, to its wing; hence the first law of aerodynamic design must always be a clean and uncluttered wing, free of all excrescences. The turbo-jet power plant, when packaged around the centre-line, obviously led towards that ideal and, moreover, reduced the asymmetric control problems at the same time.

F. Pilling (Metropolitan-Vickers Electrical Co. Ltd., *Associate Fellow*): If aircraft designers were content to spread piston engines, with their enormous propellers, along the wing, surely they should welcome the small diameter of the jet engine, which allowed them to make use of a very compact design, especially bearing in mind the great thrust which was available from the jet engine as compared with a piston engine of the same diameter.

S. H. Evans: That was exactly the point he had been trying to make. Apparently, Mr. Pilling had misinterpreted his remarks as a case *against* jet engines, when actually he was trying to show that airframe designers had not yet taken full advantage of their possibilities—to judge from what they had been promised in the near future. His own conception of the future envisaged a multi-jet power unit totally submerged in a long-chord centre-section, with the jets exhausting from the wing in a horizontal knife-edge, rather than through "barrels." Perhaps some other designer would like to comment on that.

G. J. Armstrong (National Gas Turbine Establishment, *Assoc. Fellow*): Having somewhat vivid recollections of the struggle to obtain fuel injection into the reciprocating

engine, much less injection in the right place, he was not particularly impressed by the progress made by the Accessory Industry so far, relative to the turbine. After all Whittle contrived to inject the fuel and, where he wanted it burnt: the Industry had only to start from that point!

Both Dr. Watson and Mr. Lubbock had referred to burners. This was not surprising since the type of fuel control system to be used in a given case was bound up with the type of burner to be used. Mr. Lawrence referred particularly to swirl.

The spill burner, which exploited the advantages of swirl in a particular way, had a special characteristic, *i.e.* good atomisation over a large flow range for a small range of pressure at entry to the burner. Unfortunately application was not without its difficulties and thus, although at Whetstone using the spill burner they had found it possible to idle a W2/700 engine quite stably down to 2,500 r.p.m. (top speed 16,750 r.p.m.) with a fuel flow of something less than 4 lb./burner/hr., the jet pipe temperature being then uniform and not higher than 450°C., they were still concerned to develop a simple and reliable system to go with it which would enable the starting and stopping operations, for example, to be accomplished cleanly and consistently—essential functions mentioned by Dr. Watson in the paper which he had presented to the Institution of Mechanical Engineers.

A more serious matter, and one raised at a meeting of the G.T.C.C., was the accuracy within which manufacture was possible. Clearly, if accuracy were impossible except by resorting to impossible methods, not only was the burner damned but so also was expenditure of effort on the larger issue to which reference had already been made. To put this another way, if the inherent simplicity of the mechanism of the burner could not be reflected in a simple system then it was not logical to introduce corrections into the system, unless these were in themselves inherent: whether this could be done without unacceptable complication was doubtful and in such circumstances it might be wiser to examine other means of obtaining similar, if not better, spray characteristics. Therefore, ignoring for the time being patternation and related factors, they had been concerned also

TABLE—RESULT OF PRELIMINARY RIG TESTS ON SPILL BURNERS

Burner No.	Inlet pressure lb./p.s.i.	500						*Remarks*
	Spill pressure lb./p.s.i.	250	50	40	30	20	10	
1		234	6–11	5–7	5–0	4–2	4–9	Flow in lb. & oz./hr. established by direct weighing using No. 10 Burner as master and flowing through common fuel and spill lines. All burners found badly worn on completion of tests.
2		239	6–3	5–10	4–1	3–15	4–6	
4		231	7–4	7–0	6–8	5–7	5–14	
10		240	5–1	4–12	4–4	4–2	4–10	
Burner No.	Inlet pressure lb./p.s.i.	350						
	Spill pressure lb./p.s.i.	175	50	40	30	20	10	
3		176	15–13	13–0	10–1	9–3	9–13	
6		172	13–14	10–14	9–1	7–16	7–7	
8		172	10–13	7–6	5–9	4–10	4–6	
10		172	11–13	8–8	6–6	5–10	5–7	

at Whetstone to set up a rig by means of which the rate of flow through one burner, treated as a master, might be compared to the flow through others of an identical type while subjected to common spill and feed pressures, the separate rates of flow being established by weighing. To date, only a limited range of figures was available, this being associated with the higher ratios of spill to feed pressure, *i.e.* with flows high enough to obscure errors expressed on a percentage basis.

Neilson Hancock (General Aircraft Ltd., *Associate*): Years ago they had started flying with nice simple piston engines, some even without carburettors. Over a fairly long period these engines had "collected" a number of essential accessories.

Very recently had come the introduction of the jet engine, which was to be delightfully simple, and already they seemed to be introducing a positive welter of complications.

He would appreciate an assurance from the author that they were nearing the end of the list of essential accessories for jets.

S. J. Patmore (S. J. Patmore and Partners, *Associate*): Were any attempts being made at this stage in the evolution of the turbine to create what might be termed inter-changeable standards? He had in mind such points as flanges, positioning and sizes of pipe connections, electrical connections, and so on.

An engine designer should be able to test out, without a good deal of modification, for example, some other form of injector to that which had originally been planned for the engine, or to put on some other form of starter or service either of another maker or a different mark from the manufacturer of the original equipment. In the piston engine range, the number of types, marks and models of the various accessories were legion, and frequently it was found that, to take advantage of some improvement incorporated in later designs, it had been necessary to make drastic modifications, and the lists of the various Air Ministry handbooks told a sorry story in this respect.

It was greatly to be hoped that the experience gained in the piston engine industry with all the various types and marks of non-interchangeable accessories would not be repeated in the development of jet engines.

E. L. M. Emtage (Ministry of Supply): At the present time quite a large S.B.A.C. Panel was dealing with standardisation of drives and flanges of accessories for various types of engines.

The new booster coil, which was intended to be common to both the reciprocating and the turbine engine and was to be the answer to all their troubles, had been found recently to be just not big enough for the turbine engine under certain conditions. The re-lighting of a charge when in the air was quite a big problem, very different in the case of the turbine from that of the reciprocating engine. Perhaps one day they would have a gadget which would indicate when a burner was about to go out and probably would take action automatically to prevent that happening.

If he had understood Dr. Watson rightly, he was at variance with him on the matter of actual starting. He did not believe in the small starter for the big turbine engine, for the reason that the engine had to be started quickly; it was of no use turning it over slowly for a long time, for that just would not do. Apart from that, in an interceptor type of aircraft it was necessary to make a clean start in two seconds. In the case of some of the biggest engines, running up to a self-sustaining speed in two seconds meant a horse-power of 500 to 600; and if they had to use a 500-600 h.p. battery, with all the maintenance and service that that would require, it would present quite a problem. That was the circumstance which was driving them to the cordite type of starter. Cordite was one of the smallest and lightest forms in which they could carry energy. Many people believed that that was something new; but in fact, cordite-operated starters had been the subject of experiment for many years, and the experimental charges were of very slow burning material. Work was being done with the C.A.S.R. Woolwich Arsenal on cordite with a view to evolving a starter charge which would be of low weight, cheap, and which would give high power.

What they needed greatly at the present time was:—

1. That fuel should be delivered in a form in which it was most readily ignited and in the correct place to light up the whole engine simultaneously.
2. That it should be fired by the most appropriate means which might be a

special form of spark, or thermally by hot wire.

3. That ignition and self-sustaining speeds should thereby be as low as possible so as to make effective starts with the minimum expenditure of energy in the starting system.

Mr. Adderley: References had been made to the difficulty of starting engines, because of the high inertia of the rotor and the propeller; he would like information about stopping them. To have the propeller turning for some minutes after an aircraft had landed would be a difficult problem, particularly on an aircraft carrier.

T. G. G. Newbery (Ministry of Supply, *Assoc. Fellow*): He had understood Mr. Lawrence to say that propeller turbine control by temperature and speed would be the best means, but that control of the propeller by temperature was better than control of the propeller by speed, because of the slow response of the propeller to speed change. He queried that; he did not speak with any authority on the temperature control aspect, but his impression was that one of the difficulties had been to obtain a means of control which would give sensitivity and also quick response. On the other hand, with the speed control of the propeller it was assumed that the engine would change speed very quickly and that the propeller would be unable to change pitch quickly enough to cope with it. Perhaps there had been some confusion of thought over the change in numerical values rather than in regard to the percentage change of speed. One of the factors which was likely to affect the problem very much was the high inertia of the turbine engine, as the result of which it was likely that the engine speed change would not be so rapid as had been asumed, and consequently the normal C.S.U. type of control which they had on the piston engine would be quite sensitive enough.

Also, if the pitch change control were made too rapid, "hunting" would result, so that a control which was too sensitive would respond too quickly and might be even worse than one which was perhaps a little on the slow side.

The Chairman: He wished that Air Commodore Whittle could have been present to hear Dr. Watson's remarks and description of the superior characteristics of his early engine as compared with the modern ones! They would hope that, if they must have more complicated and more powerful accessories, at least they would be kept light; and it seemed that, in describing the cartridge starter, Mr. Lawrence was keeping that characteristic in mind.

T. Clapham (Ministry of Supply) *contributed*: Reference had been made to the Austin Seven starter motor used on Whittle's famous engine and to the 400 h.p. cartridge-operated turbo starter at present under development. The most powerful cartridge-operated turbo starter at present in use was about 130 h.p.

For the benefit of those interested in starters from a user's aspect only, he would explain briefly how this increase in power had come about during the few years turbine engines had been under development.

The essential requirements were that the starter should be light in weight, compact in size, economical as regards consumption of petrol, electric current, cordite and so on. It should have a working life at least equal to that of the engine on which it was installed, and be capable of starting the main turbine with unfailing regularity in all climates with temperatures ranging from tropical to arctic (−40°C.).

With these requirements in mind, the main factors affecting the design of starters (size and power), and deciding the type of starter (electric motor, internal combustion engine or cordite-operated turbo) which could be used efficiently and economically were as follows:—

(a) Moments of inertia of the turbine rotor, including propeller if fitted.
(b) Igniting and self-sustaining speed of main turbine.
(c) Time required, or permitted to accelerate the turbine rotor from stationary to self-sustaining speed.
(d) Power required to overcome oil at low temperatures, in bearings and reduction gears of propeller turbine.
(e) Power required to accelerate auxiliaries.

In the case of the Whittle turbine, (a) was quite low, (b) probably 800-1,000 r.p.m., (c) probably 30 to 40 seconds with (d) and (e) very small or not present; therefore a small starter motor provided sufficient power to start the engine.

Since this early combination of turbine and electric starter motor, moments of inertia

had risen to some 400 lb./ft. and the time to accelerate from stationary to self-sustaining speed had been reduced from 30 to 40 seconds to two seconds. The increase in inertia was obviously a result of larger engine rotors, the fitting of propellers, and the use of accessory drive gearboxes. The reduction in acceleration time was necessitated by the importance of getting high speed Service aircraft airborne in the shortest possible time.

As examples of the power required for starting purposes consider two turbine engines, examples (1) and (2) with moments of inertia of 41.8 and 386 lb./ft. respectively.

The horse power required to accelerate these engines to their respective starting times were approximately:—example (1) for 30 seconds start 4 h.p., for two seconds start 21 h.p.; example (2) for 30 seconds start 40 h.p., for two seconds start 130 h.p.

It would be seen from these examples, that when the starting time was reduced from 30 to two seconds the power required to accelerate the turbine increased considerably. Either a starter motor or an internal combustion engine to give the power required to start the engine represented by example (2) would not be a practical proposition. Even if the starting time were extended to 30 seconds, neither of the two methods could be considered for an aircraft installation, therefore, some other concentrated source of power had to be sought.

Various methods of starting had been tried, such as gases from liquid or solid propellants (*e.g.* hydrogen peroxide or cordite), directed on to the main turbine blades by means of auxiliary guide vanes, vane type motor using compressed air or gas generated by an ammonium nitrate cartridge, internal combustion engines and cordite-operated turbo starters of which several designs were in course of development. The cordite-operated turbo starter was the most compact and powerful starter at present in use, for instance, a turbo starter to start the engine represented by example (1) in two seconds would use 220 grammes of cordite and weigh about 30 lb., including a three cartridge breech; a similar type starter to start engine represented by example (2) in two seconds would require some 720 grammes, and the starter and breech would weigh about 50 lb.

L. A. W. Newman (*Associate*) *contributed*: Comparative figures would be interesting of the necessary accessory weights for current piston engines and turbines.

It was realised that the actual weight might vary with engine size, but expressed as a percentage of engine dry weight there was probably only a small difference in the figure for turbines in the same thrust category.

Also, could Mr. Lawrence give figures of the individual and collective bleed of b.h.p. to drive the various engine accessories? In this case, to quote these losses as a percentage of total developed h.p. would show the piston engine in an unfavourable light because of its vast difference in output from that of the turbine.

In the gas turbine they had a beautifully simple means of obtaining high power outputs and he would plead that every effort be made to keep it that way.

MR. LAWRENCE'S REPLY

Dr. Watson: He agreed with his diagram of fuel and excess power plotted against r.p.m. except that, unfortunately, the range of operation over which the blowers operated efficiently was so narrow that the curves were rather more "peaky" than he had shown. This meant that small errors in matching the two factors would be quite critical.

The points raised about the dual task of the igniter plugs, both of vaporising the spray and igniting it, were interesting; the alternative solutions did sound involved and he felt sure that everyone would be more than thankful if the high tension ignition system could be replaced by a simple D.C. low voltage heater wire! He felt, however, with Mr. Lubbock, that the simple hot wire igniter might not be a good solution, but thought that Dr. Watson might be referring rather to a combination of heater wire and spark ignition.

Mr. Lubbock: Regarding the alleged disinclination to use complex burners, the matter was really very simple. During the war, there had been a great urge behind development work and it had been found easier to develop the pump and fuel system generally to cope with higher pressures than to develop and manufacture complex burners with the required accuracy of performance. In the early days, the ceiling of the jet aircraft had not been so high and consequently, the range in fuel flow which had to be covered was not so great; also, the importance of very fine atomisation had not

been appreciated, so that the pressure range which had to be met did not then appear insuperable. The early engines used the mechanically variable slot type burners, and with these some trouble was experienced with sticking, although it got progressively less as experience with the engines was gained; but he felt it might recur with the granules of dirt which Mr. Bass and Mr. Lubbock had promised them in future deliveries of fuel.

Nevertheless, from the earliest days, an impressive programme of research had been mounted on the fundamentals of atomisation and on the design of complex burners. One difficulty with regard to the various types of burners was in connection with the cone angle. The combustion engineer was rather extreme in his requirements, both in regard to ultra-fine atomisation and cone angle, and obviously he was right; his requirements had to be met if the best results were to be attained. But in any of the variable slot burners—the Lubbock, Duplex or the Spill—there was a change of cone angle; that must be considered and a compromise effected. The Duplex was the type of burner with which they had most experience and of which they were manufacturing quite a number at the moment. This design had some manufacturing advantages in their view and also, having no moving parts was not liable to stick.

Mr. Worcester: A "wet" start was the name given to a start when the flame tubes were already wet with fuel from a previous faulty start. The dump valve action was adopted primarily to reduce the degree of wetness of starts under certain conditions. So, too was the provision of pipes connecting the lowest possible points of all combustion chambers to an atmospheric drain; a very low pressure relief valve was fitted which shut off the drain as soon as any reasonable back pressure in the combustion chambers (blower pressure) existed.

Regarding "the flash playing around the jet pipe," Mr. Worcester should have seen American jet engines start! The flame was then 10/10 and quite long. The American philosophy, as explained to him, was that the initial burst of flame was not so serious as a hot acceleration, and for that reason they tied down the speed of acceleration far more than was done in Great Britain. British ideas had been that the flame should be reduced as far as possible without compromising the engine's starting under other conditions.

Mr. Bass: He was grateful to Mr. Bass for bringing up the question of the type of fuel with which they would have to contend. Gas turbines so far had been using so little fuel that a very special type could be supplied, cleaned and dusted! He had to confess that he had been hoping that the trend would have been to heavier fuels, using some better means of atomisation and lagged fuel tanks in order to cope with the cold at the high altitude. After all, bomber aircraft had had some very good thermal insulation on their tanks, even if it were applied in order to prevent incendiary bullets causing explosions.

In view of the general dictum that fuels that could be supplied readily were of high volatility, work was proceeding to make the fuel system swallow petrol and other noxious liquids.

Mr. Bass's point regarding the separation of ice from the fuel at low temperatures was of great interest. In fact, when tests had been undertaken in the refrigerating chamber on the fuel system, this trouble had been encountered as an incidental difficulty, although at the time it had not been established from where the water, or rather ice, had come. He could see no easy solution to the filtration problem, for the types of burners which were required for good atomisation comprised small holes and these must not get blocked. Air injection, if it could be developed into a practical system, would provide the most probable source for alleviating the problem.

Mr. Evans: He agreed about the undesirability of cutting out engines asymmetrically and sympathised with him in the solving of the control equations. Nevertheless, it seemed to him that if there were all that number of engines, it might not be such a hardship to cut out two engines symmetrically.

He must confess he had always had a hankering for a central engine room, as on board ship, and the potentialities of enormous powers from the gas turbines brought this dream nearer, but perhaps for its fruition it must await the all-wing aircraft, so as to allow a free and unrestricted path for the large volume of hot gases through the "fuselage."

Mr. Armstrong: The points raised in connection with the spill burner were, he

thought, covered to some degree in the main paper. The reply to Mr. Lubbock about the difficulties with cone angle variation were also germane to the subject. There was no doubt that the spill burner was an attractive burner, but it had its foibles and detractions which had to be considered. The other detractions were the more elaborate control system that was required—for this had to meter the difference between the flow supplied to the burner and the flow that was spilled. The difference between too large quantities was always difficult to control reasonably. It would probably be essential to resort to a "closed loop" type of control system in this case. The last difficulty was the one to which Mr. Armstrong referred; that of running a number of burners in parallel and seeing that their deliveries matched within the rigorous limits that the engine demanded.

The figures which Mr. Armstrong had supplied bore out this. However, he rather understood that the tests had been made on burners which were immediately available, and that on strip examination after completion of the tests they were found to be in bad condition, so that the tests could not be considered quite representative. Nevertheless, there was obviously a long way to go to get down to tolerances of the order of ± 2 per cent.

Mr. Hancock: While sympathising with the plea for simplicity, he had no wish to give the assurance asked, as it would imply that his own congenial job would be coming to an end! But he felt that Mr. Hancock was mixing up the real and the unreal. He thought that the actual pieces of equipment employed on the engine were relatively simple. They had to be made with the care and accuracy required of all aircraft parts, but in themselves were not so complicated. The complexities came in the mind of the designer and he regarded it as a tribute to his eloquence in putting over the difficulties and problems involved that Mr. Hancock should give them physical substance. The figures given in the reply to Mr. Newman showed that the simplicity and light weight of the whole jet engine had been matched by the accessories.

Mr. Patmore: His point was dealt with by Mr. Emtage with more authority than he himself could command.

Mr. Emtage: He fully endorsed the statement that the booster coil performance was not good enough to cater for all conditions. This might not all be the fault of the booster coil, or rather, it might be easier to improve the performance by adopting, for instance, Mr. Bass's suggestion of a more volatile fuel for the torch igniter. The whole subject was complex and required clarification as the result of a comprehensive research programme.

He was very glad of Mr. Emtage's backing and faith in the cordite starter. He himself believed it had great potentialities; the avoidance of hot starts with the possible damage to turbine blades which that could imply would be of importance, the quick starting of heavy engines, the absence of dependence on ground trolleys and so on, all these assets had a definite financial value.

Reference had been made to the light weight of these starters. The unit in the picture had been made in the first case purely as a mock-up unit to obtain experience of the performance of such starters. Consequently it was deliberately designed on the heavy side in order to conduct away the heat better and to cater for any unknown stresses to which it might be subjected. The overall weight even of this unit was under 40 lb.

Mr. Adderley: He was afraid Mr. Adderley had him at a disadvantage; he supposed that it would be necessary to fit a brake on the propeller shaft for an aircraft for carrier operation. But, before an engine could stop, it would have to start, and the problems involved in starting them were difficult enough for the moment.

Mr. Newbery: The object of employing temperature control to vary the propeller pitch on a propeller turbine engine was so that the engine speed, which was the most important point, could be controlled quickly. The fact that both the propeller and the temperature control took a short time to alter the pitch setting, was neither here nor there. He had shown in Fig. 6 that for stable operation the speed must be controlled more quickly than the temperature. This would avoid the "hunting" trouble.

He had it on good authority that it was usual for the piston engine to over-speed on acceleration by 20 to 30 per cent.—in fact a case had been quoted where the over-shoot had been 50 per cent. In the gas turbine world, a 5 per cent. over-shoot would be

regarded with grave disfavour. As regards the speed of acceleration, it was not generally realised how vast were the powers available from the gases for acceleration or deceleration. For instance, on a jet engine, producing say 4,000 lb. thrust, the maximum power to drive the compressor was around 7-8,000 h.p. In accelerating from a thrust rating of 2,000 lb. up to a maximum speed and assuming that the change in fuel took place instantaneously (which, of course, it did not quite) some 3,000 h.p. would become available for acceleration. In spite of the high inertias of the engines, the accelerations still took place very quickly.

Mr. Newman: He was grateful to Mr. Newman for asking for comparative figures of accessory system weights between the turbines and the piston engines. He had himself been surprised at the extremely favourable picture the figures showed. Two jet engines were compared against two liquid-cooled piston engines, the figures being expressed as percentages of the engine dry weight.

	Piston Engine		*Jet*	
	A. %	B. %	C. %	D. %
Fuel system	4.2	4.4	6.5	7.2
Ignition	3.2	2.5	0.2	0.2
Lubrication	1.4	1.2	2.3	0.4
Coolant	1.3	1.1	—	—
Starter	1.0	2.3	1.5	2.3
	11.1	11.5	10.5	10.1

The piston engines had been considered without their propellers. Moreover, in one of the jet engines, the weight of the oil tank was included since it was integral with the engine and not a separate part. In view of the great reduction in overall weight between comparable piston and turbine engines, the fact that the turbine engine accessories weighed less on a percentage basis, showed their inherent simplicity and extreme lightness.

There were only two engine accessories needing power to drive them—the fuel pump and the lubricating pump. The power required for the latter could be considered negligible, while that for the burner could be computed readily. The engines normally developed approximately ten times their fuel consumption (in gals./hr.) as useful power. The fuel pump turned 90 per cent. of the mechanical input of power into hydraulic h.p.

Therefore the mechanical power input to the pump per s.h.p. developed by the engine was given by

$$\text{Input h.p.} = 1.3 \times 10^{-6} P.$$

In this equation P stood for the fuel pressure in lb./sq. in. against which the pump was delivering.

Mr. Clapham: He thanked him for his clarification of the overall picture concerning turbine starters. There was little which he could add or on which he could comment.

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THE NATURE OF THE DISTORTION OF SWEPT-BACK WINGS

by

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SUMMARY.

THE distortion of straight wings is simple and familiar; upward bending causes slight changes in dihedral angle and loads offset either fore or aft of the flexural axis cause twisting, which involves changes in incidence. When wings are heavily swept back, bending causes change of incidence as well as change of dihedral angle, while the changes of incidence due to twisting are no longer equal to the angles through which the wing structure twists.

With a straight wing, a loading point on each rib can be found to give bending but no twist; with a swept-back wing a similar point can be found, but although there is no twist at the loading section, yet there is twist at all other spanwise sections; the twist rises progressively from zero at the loading section to a maximum and dies away again towards the wing root.

The conception of a "flexural axis" applicable to a straight wing must give way to a "locus of flexural centres" on a swept-back wing, but, by reason of the type of distortion outlined in the preceding paragraph, even the "locus" is of limited value.

As examples of this general analysis, the associated twist and bending of a simple swept-back wing structure are given for the condition of zero change of incidence under load, and the locus of flexural centres is drawn for a simple form of wing structure with 45° sweepback.

1. THE SIMPLIFIED "STRAIGHT" WING.

The wing structure of a present-day conventional aircraft is a cantilever under a system of loads spread out more or less along its length and usually slightly offset in a fore and aft direction from the centre of the structure. Let us examine the effects of loading the structure by looking first at the simplest possible form, a girder of constant cross-section consisting of two equal and parallel independent spars fixed rigidly at their roots and projecting perpendicular to the plane of symmetry of the aircraft; the spars are assumed connected by ribs pin-jointed at their ends to the spars themselves.

The loading system in normal flight may be said to consist of a distributed air load which for our purposes may be considered as concentrated at the centre of pressure of each chordwise section, and a series of relieving loads due to the weights of the wing structure itself together with such items as undercarriages, engines and tanks mounted on the wings. All these loads act more or less up or down, that is to say their component normal to the girder is much greater than their tangential component, and in all the following analysis the tangential component has been neglected as being relatively unimportant.

Now the wing structure has an axis, known as the "flexural axis," which is a straight line situated mid-way between the two spars forming the girder; any load applied on the axis will cause bending of the structure without twisting it, but any load offset from the axis will produce both bending and twist. It is important to note here that twist takes place not only at the section at which the offset load is applied, but also at every other spanwise section, although not of course to the same extent. Another point to be noted is that if at any spanwise point the structure has twisted by 1°, then there is a change of incidence of 1° at that point; this is so obvious that it does not seem worth mentioning, but the object of doing so will appear at a later stage in the argument.

2. ACTUAL WINGS AS USED ON AIRCRAFT

Although the effects of loading which have been described are strictly applicable to a uniform girder projecting at right angles to

the plane of symmetry, they are also approximately true for actual aircraft wing structures with taper and small amounts of sweep, either forwards or backwards. It is when we come to consider the large angles of sweep-back of the order of 45° that secondary effects grow to be of prime importance.

Considerable confusion has existed in the minds of many workers in this new field, as evidenced by the mistaken ideas which have been expressed, particularly on the supposed position of the flexural axis of swept-back wings. The somewhat long-winded nomenclature has not helped towards a clear understanding of fundamentals, and although the new approach which is now to be made to the matter may appear to some to be unduly light-hearted, no excuse is offered for following in the footsteps of such a man as Galileo.

3. ARTHUR AND SAM.

At this stage, two characters new to aeronautical science appear, Aerodynamic Arthur and Structural Sam; they have not turned up before because in the past their viewpoints were identical. With the advent of heavily swept-back wings, this is no longer the case.

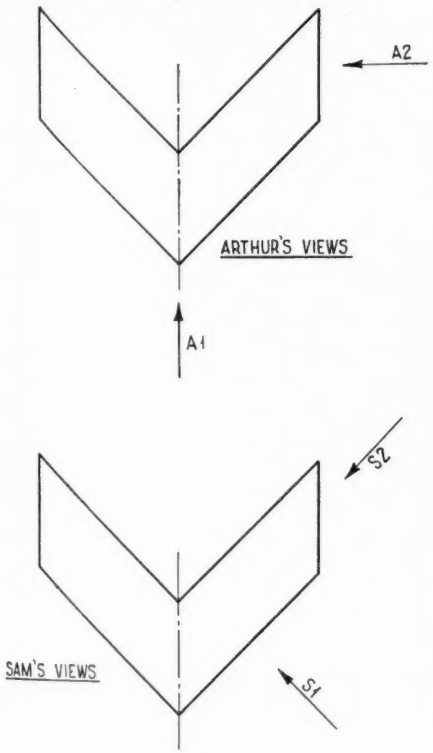


Fig. 1.

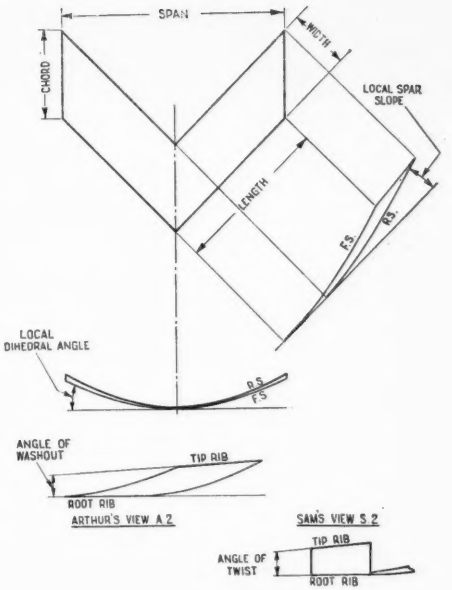


Fig. 2.
Simplified swept-back wing deflected by lift loads.

Now Arthur is particularly concerned with three views of any aircraft, each view being at right angles to the other two. He looks along the wind direction and sees the aircraft in a head-on position; he looks at it in side view and sees particularly the wing sections and wing incidence, and he also looks at the plan view of the wing.

Sam, on the other hand, takes no thought of which way the relative wind is blowing over the surface, but can think of his structure at rest with loads upon it, just as if it were under static test in his laboratory. When he contemplates the wing structure, he also takes three views, mutually at right angles; he sees the wing girder as a cantilever with what may be called its length or overhang running from root to tip. He therefore takes as one of his most important views everything he sees when he looks at right angles to the length of the girder; he also looks along the length of the girder to see the section which is available for resisting torsion, and he takes a plan view to see among other things the points of application of the normal loads which give rise to the torsion, see Fig. 1.

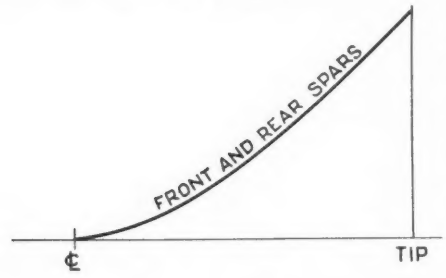
It will now be clear why Sam's and Arthur's views of the aircraft are identical on aircraft without sweepback, and increasingly divergent, except of course for the plan view, as the angle of sweepback grows. We must now study why it is important to distinguish between Sam's and Arthur's views of the heavily swept-back wing, and this brings us to the distinction between twist and incidence change, or washout, between root and tip.

4. DEFINITIONS OF WING GEOMETRY

Before proceeding with the argument, however, it will be profitable to pause for a moment and decide on some definitions of the geometry of the wing; these are given in Fig. 2, and are really self-explanatory. Span, chord, angle of washout and local dihedral angle are Arthur's concern, and length, width, twist (positive when the front spar is higher than the rear) and spar slope (positive when the tip is higher than the root) are Sam's; with zero sweepback, these two sets of terms are, of course, synonymous.

5. THE DISTORTION OF THE SIMPLIFIED SWEPT-BACK WING.

Consider now the simplest possible case of the swept-back wing, with two equal parallel spars of constant section, and imagine that the contribution provided by the torsional



ARTHUR'S VIEW A1 OF HALF SPAN

Fig. 3(a).

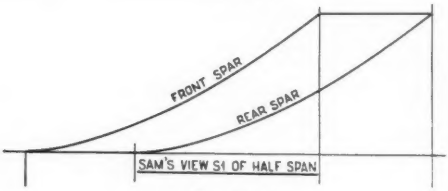


Fig. 3 (b).

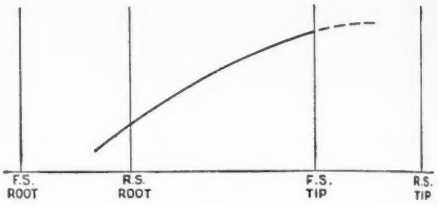


Fig. 4.
Twist for zero washout.

stiffness of the ribs and covering is negligible compared with that due to the differential bending of the spars. Suppose now that a single rib running fore and aft, that is in the direction of flight, is simply supported by its tips on the two spars and carries a single up load at its centre point. The two spars will deflect equally, and Arthur's view (A1) of the deflected wing structure will be shown in Fig 3(a), and Sam's view (S1) as in Fig 3(b). Arthur says that the distortion consists of increased dihedral everywhere with zero washout, but Sam says that he sees the local spar slope increasing from root to tip, *i.e.* bending of the girder, coupled with positive twist, since the front spar is always above the rear spar, and this deflection difference, that is to say twist, increases towards the tip. If the twist be plotted at all points along the length of the wing, Fig. 4 results. Although the exact definition of twist near the root needs further study, this diagram provides an interesting illustration of the way in which one particular problem in the design of swept-back wings might be solved. Supposing Arthur wants a wing which will bend without washout, he must tell Sam to design for a twist at any point along the span as shown by Fig. 4. Twist and washout are thus very different things on a swept-back wing.

Sam is now faced with a certain quite definite structural problem; as he sees it, he must provide torsional stiffness at each section which is related in such a way to the bending stiffness at that section that the total disortion under the given loading will meet Arthur's specification. This statement is general, and is not limited to the plan form of the particular wing, nor to the wing structure so far described.

It is worth while at this stage to turn back to the conventional structural approach to the distortion problem by looking for the flexural axis. Taking the simple swept-back wing consisting of two equal spars of uniform section, with the load applied on a single pin-

jointed rib running fore and aft, we have seen that a centrally applied load on the rib gives zero washout, as Arthur sees it, but positive twist as Sam sees it. If we are to find a position of the load for zero twist, it is clear that the load must be moved somewhat towards the rear spar. Now assuming that the front spar always extends in an unloaded condition outboard beyond the rib, wherever it may be, it is easy to calculate the position of the load on the rib which will give zero twist.

Zero twist has been defined for simplicity as zero slope on a line, called the reference line perpendicular to the spars through the mid-point M of the rib which is being loaded at a point P, see Fig. 5. It must now be noted

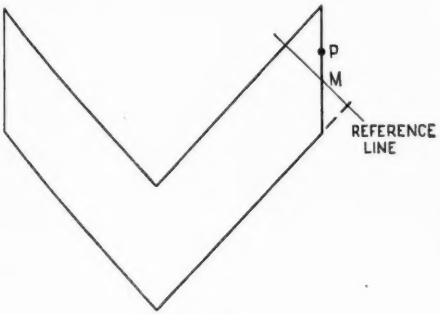


Fig. 5.
Definition of zero twist.

that zero twist at this point does not mean zero twist at all other points, since the front spar is, except at the reference line, always above the rear spar, thus producing positive twist all along the span, dying out to zero at the loading point, see Fig. 6. Although the difference in spar heights is not very large, it is probably too large to be neglected if the sweepback is appreciable; this characteristic of the swept-back wing, namely that a single load can only produce zero twist at one point along the span, is to be contrasted with the much simpler form of distortion of the straight wing where zero twist at one point means, to a very close approximation, zero twist everywhere.

6. LOCUS OF FLEXURAL CENTRES.

It is not, therefore, strictly true to speak of a "flexural axis" for a swept-back wing; instead we can speak of a "locus of flexural centres," *i.e.* a line joining the points P when the rib is placed at successive positions all

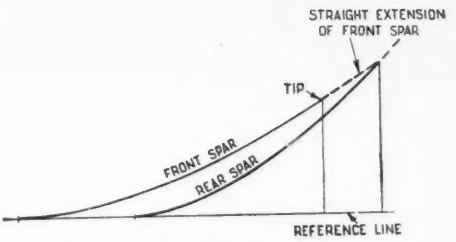


Fig. 6.
Sam's view of half wing loaded so as to give zero twist at reference line.

along the span; even this must be limited to mean the locus of the loading points where no twist occurs actually at the point of application of the load. It does not mean that if a swept-back wing is loaded all along the locus of flexural centres it will have no twist.

As an example, a calculation has been made of the locus of flexural centres for a simplified wing with equal uniform spars of 45° sweepback and a single pin-jointed fore and aft rib to which the load is applied. The result is given in Fig. 7, from which it will be seen that the locus lies behind the half-chord line (often assumed as the correct position) particularly near the wing root where it runs back to the rear spar attach-

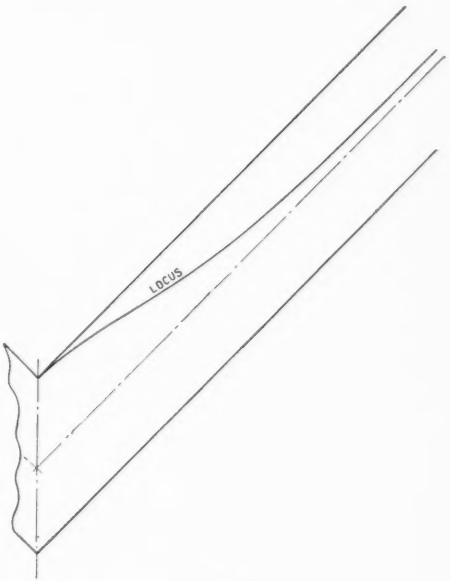


Fig. 7.
Locus of flexural centres. Ribs along wind.

ment point. This is obvious from physical considerations, because the length between the front spar root and the reference line is greater than the corresponding measurement on the rear spar, particularly near the wing root.

The locus of flexural centres is not even approximately a straight line, whereas an "axis" is essentially a straight line; thus it seems reasonable to suggest that the term "flexural axis," although it may be used as a conversationally convenient term, has no strict application when studying the distortion of wings with appreciable sweepback.

CORRESPONDENCE

ENEMY JET HISTORY

The pre-history as stated by Mr. Maguire (January 1948) is rather short but inaccurate. The correct appreciation of the possibilities of turbo-jets goes back to investigations of W. G. Noack, an eminent research engineer of the Brown-Boveri Co. A survey of his original investigations was contained in a paper read in May 1920 in Berlin. In this the pioneer effort of H. Coanda (Ducted Fan, 1910), the possibilities of the "Trompe Propulseur" of Mélot (thrust augmenter, 1916), and the jet-propelled wing were subjected to a critical investigation. Noack established that, at very high speeds and/or very high altitudes, jet propulsion by way of constant-pressure gas turbines could become practical. He devoted many years to the perfection of exhaust-driven gas turbine superchargers based on principles established simultaneously by Rateau and by the Royal Aircraft Factory. He and Chr. Lorenzen were responsible for the introduction of hollow, internally cooled, turbine blades.

Engineering authorities of the "Heereswaffenamt" later reviewed the position of jet propulsion in respect to thermal and propulsive efficiency. It was found that because of the admissible temperatures for turbine blades and combustion chamber, the thermal efficiencies would be necessarily poor, and the scheme could be considered only when the speed of flight exceeded 300 m.p.h. At about the same time, Crocco showed in a detailed investigation that speeds of the order of 800 m.p.h. might be assumed practical for direct thermal jet propulsion.

Early in 1930, the ducted radiator (an invention of H. Junkers, 1914) was subjected to theoretical investigation. At the same time, Oestrich of the German Research Laboratory D.V.L. proved in a brilliant survey that appreciable thrust could be expected by exhaust ejection at flying speeds and altitudes then predictable. Consequently, the Institute for Research on Propulsion, of the D.V.L. devoted special consideration to problems of thermal jet propulsion and to gas turbines. K. Leist recommended and experimented with internally cooled blades. The results of all this research work became so encouraging that thermal jet propulsion by way of gas turbines could no longer be disregarded by the authorities responsible for development. In addition, the patents of F. Whittle and of Alf Lysholm indicated clearly that outside Germany the merits of thermal jet propulsion were being recognised. Even the old gas turbine pioneer Hans Holzwarth became convinced that direct reaction drive for aircraft with gas turbines was "just around the corner."

Thus it was but a logical necessity that the engineers in the administration of the German Air Ministry responded.

In respect to the development of jet engines by the Heinkel Works, some credit ought to have been given to Max Hahn whose early designs (*vide* his patents) contained all the characteristics of the Heinkel turbo-jets with centrifugal compressor, annular combustion chamber and reverse flow. This design was actually the He.S3 jet engine.

It would have been fitting to give the correct name of an eminent aerodynamicist like Professor Albert *Betz* (instead of "Beitz") who has been for so long connected with the work done at Goettingen. Betz's work on aerofoil cascades and axial compressors goes back more than 25 years, and it has actually been his work (in connection with the practical experimenting at the D.V.L.) which created the basis for the adoption of axial-flow compressors for the German jet engines (*vide* his 1938 paper, translated as N.A.C.A. Techn. Memorandum No. 1073).

The reference to the scarcity of traces of Campini's earlier work appears of little justification: in January 1938 S. Campini communicated a detailed description of his work together with the underlying theory (*vide* "Sulla Teoria Analitica Del Moto-Propulsore Campini," L'Aerotecnica Vol. XVIII No. 1, Jan. 1938, p. 18; translated as N.A.C.A. Techn. Memorandum No. 1010). Actually, his studies of the subject of jet propulsion go back to 1929, and part of his investigations were published in 1930 (the omission of parts

of the paper seems to have been demanded by the Italian Air Ministry which had brought him into contact with the Caproni firm). Moreover, essential design features were given in patent specifications published before 1939.

I should like to add the critical remark that historic accounts of engineering development are not well based on interrogation reports compiled by teams who were professionally better equipped than linguistically. The mis-leading and contradictory impressions conveyed in many official reports on enemy progress are doubtless due to the interrogation of minor star performers whose faculty to speak English and whose eagerness to proffer information were obviously ill-matched by their professional abilities and by their modesty. In turn, this has led to some regrettable mistakes in selection.

A. R. Weyl, Associate Fellow.

A SUGGESTION FOR EXCHANGING INFORMATION

Many thanks for the List of Members recently received. I am sure that there must be many others similar to myself that have been away from the "Old Country" for many years, that have browsed through it and have found references to old friends and acquaintances of former years that have brought many nostalgic memories.

Having resided for a few years in Iraq, Egypt and Malta during my service with the R.A.F. several years ago, I have contemplated writing to some of the listed members in such far away places, to institute an exchange of aeronautical chats, as, from my own experience, I know that it can be a very lonely life, and the mail is a great thing to look forward to.

After all, one of the objects of the Society is "to promote the Species of Knowledge which distinguishes the Profession of Aeronautics," and what better way is there of accomplishing such spread of knowledge than an exchange of information between a member such as myself in an often sub-arctic atmosphere and a member in China or New Zealand, of which countries I must confess I know nothing of flying conditions.

Such a correlation of information I am sure would be very educational, and possibly could be compiled into many good joint articles for the JOURNAL.

May I take the liberty of suggesting your devoting a small paragraph in the Monthly Notices or the JOURNAL sometime, to this idea and see if any other members would be interested in instituting this correspondence scheme.

It would, I am sure, be very helpful for potential pilots and aircraft designers to know more about the geographical and meteorological conditions in foreign lands and would incidentally improve that camaraderie that should, and does, exist between all those who are interested in air transport.

Thos. G. Cribb, M.I.Ae.S., A.R.Ae.S.

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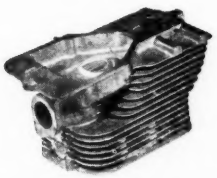

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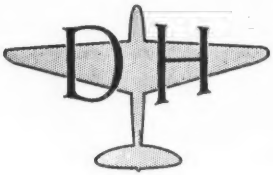

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